STUDENT RESEARCH AND PUBLISHING PROGRAM IN
SECONDARY SCHOOL SCIENCE
A STUDY OF ITS EFFECTS AND
DEVELOPMENT OF A MODEL FOR IMPLEMENTATION

Jonathan Lee Eales

A Dissertation Submitted in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in Educational Leadership
Graduate School of Education
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Dissertation Title: STUDENT RESEARCH AND PUBLISHING PROGRAM IN SECONDARY SCHOOL SCIENCE: A STUDY OF ITS EFFECTS AND DEVELOPMENT OF A MODEL FOR IMPLEMENTATION

By: JONATHAN LEE EALES

Field of Study: DOCTOR OF PHILOSOPHY IN EDUCATIONAL LEADERSHIP

Dissertation Advisor: DR. SANGOB LAKSANA

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ABSTRACT

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Key Words: STUDENT RESEARCH, STUDENT PUBLISHING, SECONDARY SCIENCE, AUTHENTIC SCIENCE

Name: JONATHAN LEE EALES

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The Student Research and Publishing Program (SRPP) in Secondary School Science is a program, embedded in a standard science curriculum, which requires students to design and conduct authentic, original research, and offers them the opportunity to publish their work in an entry-level, peer-reviewed, scientific journal.

The purpose of this study was, firstly, to determine the effects of the SRPP on student outcomes in four areas: science-related attitudes, understanding of the Nature of Science (NOS), experimental research and publishing skills and attitudes, and development of 21st Century Skills. Secondly, this study aimed to develop a Model for Implementation of the SRPP into other schools.

For the first part of the study, students enrolled in an IB Physics course with the SRPP were compared with students in a standard IB Physics course with no SRPP. A series of surveys was used to gather data from both groups. It was found that the SRPP had significant positive effects on students' research and publishing skills and attitudes, as well as on students' development of 21st Century skills. However, the SRPP was shown to have no significant effects on students' science-related attitudes and understanding of NOS.

The second part of the study used two approaches. Firstly, the process and effects of a Trial Expansion of the SRPP into IB Biology and Chemistry were studied. The process of the Trial Expansion was studied through the use of a semi-structured interview with the implementing teachers, and its effects on student outcomes were studied using the same instruments as in the first part of the study. Secondly, semi-structured interviews, addressing perceived requirements and challenges of the process of implementing the SRPP in a new school, were administered to stakeholders with experience of the SRPP. The findings from the interviews, along with the results of the study of the Trial Expansion, were used to inform the development of a draft Model for Implementation of the SRPP. The final, expert-validated Model proposes a four-phase approach to the implementation of the SRPP in a new school.

This study demonstrates the benefits of the Student Research and Publishing Program in Secondary School Science established at International School Bangkok. The study also develops a Model for Implementation of the SRPP in other schools. It is recommended that schools consider implementing the SRPP using this Model in order to realize the demonstrated benefits for their students.

Field of Study: Doctor of Philosophy in Educational Leadership

Graduate School of Education **Student's signature…………………..**

Academic Year 2014-2015 **Advisor's signature ………………….**

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Jonathan Eales

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LIST OF ABBREVIATIONS

ABBREVIATIONS	MEANING
AESP	Attitudes toward and Effects of Student Publishing
MANOVA	Multivariate Analysis of Variance
BSCS	Biological Sciences Curriculum Study
CASPiE	Center for Authentic Science Practice in Education
EAL	English as an Additional Language
HL	Higher Level
IB	International Baccalaureate
IBL	Inquiry-Based Learning
IBO	International Baccalaureate Organization
ICT	Information and Communication Technology
IOC	Item-Objective Congruence
ISB	International School Bangkok
JoS	Journal of Science
MANCOVA	Multivariate Analysis of Covariance
NOS	Nature of Science
POS	Process of Science
PSSC	Physical Science Study Committee
RBL	Research-Based Learning
REU	Research Experiences for Undergraduates
SL	Standard Level
SRPP	Student Research and Publishing Program
SSRSSA	Secondary Science Research Student Self-Assessment
SUSSI	Student Understanding of Science and Scientific Inquiry
TELRI	Technology Enhanced Learning in Research-led Institutions
TOSRA	Test Of Science-Related Attitudes
URSSA	Undergraduate Research Student Self-Assessment

CHAPTER I

INTRODUCTION

Approximately five hundred years ago, humanity began what was arguably the most important transformation in our species' history, the Scientific Revolution. Over a period of several hundred years, scholars developed a new way of thinking, a new way of learning. This new way of learning came to be known as science, and its development has been one of the most important influences in modern history (Laitko, 2000). The last five hundred years of human history has witnessed the exponential growth of human knowledge, capabilities, and technologies.

In the first 10,000 years of recorded human civilization, we made relatively little progress in terms of our understanding of the world around us or in our ability to improve our lives with technology. We believed that the sun went around the earth. We had little understanding of the rest of the natural world. Ten thousand years of human effort produced technology little more advanced than clocks, sailing ships, gunpowder, and windmills.

Then, in the last 500 years, we learned about the solar system, galaxies, black holes; atoms, molecules, polymers; anatomy, cells, viruses, chromosomes, DNA; electricity, electromagnetism, quantum physics. In the last 500 years, we have developed technologies like telescopes, microscopes, functional magnetic resonance imaging; telegraphs, telephones, radio, mobile phones; vaccinations, antibiotics, radiation therapy, genetic manipulation; trains, automobiles, airplanes, satellites. We now sustain seven billion people, with typical life expectancies over 70 years. And just recently, we landed a mobile scientific laboratory robot on Mars using a powered, controlled descent. All this in just 500 years of effort, a result of this new way of learning: Science.

As evidenced by the last five hundred years of human history, the scientific way of learning is powerful and effective. As educators, it is imperative that we ensure that our students master it. And yet this has proven extremely difficult to accomplish reliably for all students. In order to provide a context within which we may place the research that is being conducted here, a short overview of some of the relevant approaches to science education of recent history will be presented.

Background of the Study

Since the beginning of the modern era of mass education, scholars have been calling for reforms in their attempts to design effective methods of teaching students how to learn scientifically (Schulz, 2009). Dewey (1910) emphasized the importance of science education and our methods of achieving it. Since the 1960's numerous programs have been conceived and developed to improve science education. Programs such as PSSC Physics, BSCS Biology, Inquiry-Based Learning, Project-Based Learning, Discovery Learning, to name a few, have paraded through our schools one after another (Aclufi, 2005, p. 20). Currently, Inquiry-Based Learning (IBL) is the dominant approach to science education, with support from the National Research Council, Learning Standards in many states in the US, and national curricula in many other countries (AASL, 2009; Hodge, 2007; NRC, 1996; Rajagopalan, Vyjayanthi & Batta, 2004; NGSS Lead States, 2013). IBL is founded on the learning theory of constructivism (Aclufi, 2005, p. 6). It has been shown that IBL, correctly implemented, is an effective method for increasing student learning (Bryant 2006; Geier et al, 2008; Llewellyn, 2005; Zion et al, 2004). Inquiry is described as having four levels of complexity in a classroom, ranging from *confirmation* inquiry, where the question and methods are provided for an activity with a known result, to *open* inquiry, where the student is expected to define an original question, design and conduct the investigation, and interpret the results (Banchi & Bell, 2008).

Science educators also believe that understanding the scientific process, improving student understanding of the nature of science, and student attitudes toward science are all important goals of science education (NRC, 2012; NSTA, 2000; Trumper, 2006; VAMSC, 2010), and IBL has been shown to play an important role in increasing student achievement in these three areas (Gröschner, Heinz, Lipowski & Seidel, 2010; Schwartz, Lederman, & Crawford, 2004). Then, there is a group of educational scholars who have studied our modern society and identified a series of skills and competencies that are crucial to the success of our students in the 21st century workforce (Silva, 2009; Trilling & Fadel, 2009). IBL has been shown to yield student outcomes that closely match these 21st Century Skills (Gengarelly & Abrams, 2009).

Yet there are scholars who maintain that IBL as currently practiced in schools is ineffective in ensuring student learning. One important issue with implementation of a Constructivist/IBL approach to teaching science is the lack of recognition of the importance of scientific content in the curriculum. IBL sometimes focuses exclusively on the process of constructing knowledge, but successful science teaching must include a balance of content and process (Chiappetta & Adams, 2004). Without sufficient mastery of the content, students cannot hope to master the process of scientific discovery (Bryant, 2006; Kirschner, Sweller & Clark, 2006; Mayer, 2004).

Scientists are described as experts, and a basic characteristic of expertise is having a mastery of the current knowledge in the field of study. It is only with this mastery of current knowledge that scientists can successfully engage in the scientific process: mastering content is an integral part of the scientific process (Bransford, Brown & Cocking, 2000). So if we hope to educate our students in science, content must not be neglected in favor of extra time for inquiry.

Another issue is the level of inquiry that is found in IBL classrooms. Chinn and Malhotra (2002) argue that “many scientific inquiry tasks given to students in schools do not reflect the core attributes of authentic scientific reasoning” (p. 175). They maintains that much of the activity in schools that is labeled “Inquiry” is so simple as to be ineffective in ensuring student mastery of the process of authentic scientific inquiry. The key is ensuring that students engage in authentic scientific practice (Campbell, 2000; Roth, 1995; Steward, 2007; Wiggins, 1990) through all subjects and all years of the science curriculum (Geier et al, 2008).

One important effort that has grown from this understanding is Research-Based Learning (RBL). With RBL, students are given the opportunity to become part of the research team of a working scientist’s current research project. Students work in the laboratory on an assigned project that is a part of the entire research project. This can be either as a summer internship or integrated as part of a course (Osborn & Karukstis, 2009; Roach, Blackmore & Dempster, 2001). It has been shown that student involvement in RBL has positive effects on their attitudes toward science, understanding of the nature of science, understanding of and competency in the processes of science, and acquisition of 21st century skills (Guterman, 2007; Hunter, Weston, Laursen & Thiry, 2009; Seymour, Hunter, Laursen, and Deantoni, 2004).

While there is broad support for student participation in research in higher education (Hensel, 2012), there is also some concern that the current RBL model does not offer students the opportunity to fully experience the process of science. It has been shown that "problem finding", the process of identifying and defining an original, engaging, and viable research question for investigation, is crucial to success in the scientific process (LaBanca, 2008). Students in traditional undergraduate RBL are never involved in the problem finding process, as they join an existing research project for a short period (often the summer) as one member of a large team. They thus often do not feel ownership of the research. This feeling of ownership has been identified as crucial for maximizing student benefit (Dempster, 2003). It should also be noted that while RBL is widely accepted for undergraduate students, it is not commonly implemented at the high school level. But the few RBL programs that do exist at the high school level have been shown to have a positive effect on students' pursuit of scientific careers (Le, 2010; Roberts & Wassersug, 2008; Winkleby, Ned, Ahn, Koehler, & Kennedy, 2009).

One final initiative that is important to discuss here is the promotion of scientific peer-reviewed journals that publish research by undergraduates. While this is common in the social sciences, there are fewer natural sciences journals that publish undergraduate research (Reno, 2009). There are passionate supporters of undergraduate journals who argue that students benefit in many important areas from the publishing experience (Jungck, 2004). But there are also those who question whether the lack of rigor and the low value of the published work to the field mean that undergraduate journals are not worth the investment (Gilbert, 2004).

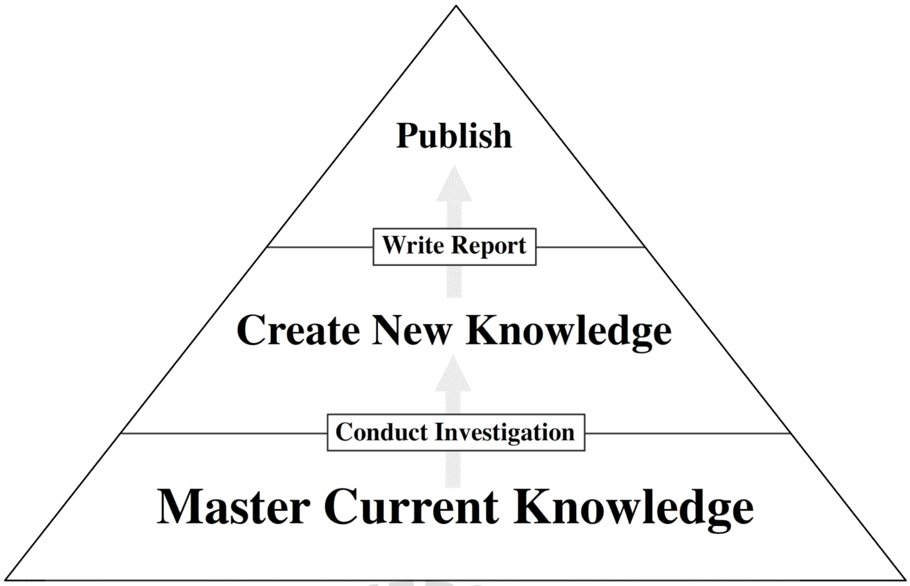
The difficulty in ensuring authentic scientific practice in classrooms was recognized by the Science Department at International School Bangkok (ISB) in the early 2000's, and led to the development of a program for teaching science which is based on a constructivist theory of learning combined with a recognition for the need for students to fully experience the scientific process in their courses. The program, termed the Student Research and Publishing Program (SRPP), has been implemented in Physics courses taught by the author since 2007. The SRPP is a program that can be implemented in any science course, integrated with the traditional content of the course. While a more complete treatment of the theoretical foundations of the program will be presented later, we will now describe the SRPP currently implemented in Physics courses at ISB.

The SRPP starts with establishing an understanding, on the part of the students, of the foundational structure and goal of the course. Students are told from the beginning of the course that the goal of the course is to learn "how to learn scientifically". All activities in the course will be focused on helping the students attain this goal.

And in order to learn how to learn scientifically, an understanding of the process of scientific learning must be established as a foundation of the course. The scientific learning process has been much studied by scholars and has been found to be varied and complex (Krajcik & Merritt, 2012; Reiff, 2004; Harwood, 2004). The students in an SRPP-based course are therefore given a simplified model of the process of science, illustrated in Figure 1.1. This model was developed by the author, to aid in students' conceptualization and understanding of the structure and goals of the course.

In this simplified model of the scientific process, termed the SRPP model of the process of science, the process of science is described as comprised of three basic parts. The first step in doing science is **mastering current knowledge**. This

Figure 1.1: The simplified SRPP model of the scientific process. (Eales, 2014).



involves learning what we already know about the world, understanding current theory. Mastering current knowledge is what is typically done in science courses throughout the world. It is accomplished through a mix of learning activities including lectures, textbook readings, problem-solving, and guided-inquiry laboratory experiments. Mastering current knowledge is time-consuming, taking up the majority of time in a secondary science course. It must be emphasized that, while mastering current knowledge is not the ultimate goal of the course, it is the foundation of scientific learning. Without it, there is no science!

Once scientists have mastered current knowledge, they attempt to **create new knowledge** through scientific investigation. The process of scientific investigation is varied and complex, involving countless procedural and analytical techniques and procedures. Much of current research on the process of science focuses on this part of the scientific process (Krajcik & Merritt, 2012; Reiff, 2004; Harwood, 2004).

Finally, if their investigations yield valid new knowledge, scientists **publish** their newly created knowledge in a peer-reviewed journal, sharing it with the rest of the scientific community so that it becomes part of the body of current knowledge. This step is crucial to the scientific process, as it serves as a way of verifying the validity of the claims of new knowledge and creates a shared scientific community of learning.

Most Secondary School Science programs focus almost exclusively on the first step in the SRPP model of the scientific process, mastering current knowledge. Students spend almost all their time learning from textbooks about what we already know, and laboratory investigations are mostly confirmatory exercises of current theory. In the SRPP, this three-part understanding of the scientific process is used as an organizing pedagogical structure for the course. Most of the time in SRPP classes is spent covering the typical content of high school science courses in typical ways. It is emphasized that this "mastering current knowledge" is not the final goal of the course, but a crucial foundation for the important next steps in the scientific process.

Students in SRPP science courses are constantly reminded, as the course content is covered, that they will go on to use the knowledge they have gained from the course content to **create new knowledge** through designing, conducting, and reporting on original scientific investigations. And then, students whose investigations have yielded valid and reliable results will be invited to **publish** a paper in the *ISB Journal of Science*, an entry-level, peer-reviewed scientific journal.

Having explained the foundational structure and goal of an SRPP course, we can turn to the details of how the goal is accomplished. The Student Research and Publishing Program can best be understood if we look at the Research part of the program separately from the Publishing part of the program. We will start with the Research part of the program.

Original scientific research, creating new knowledge, is an integral part of the science program at ISB. Starting in grade nine, all students are required to conduct one piece of original scientific research each semester. In each course, students experience a scaffolded series of laboratory investigations. While students are exposed to several methods that scientists use to investigate the world, including modeling, simulations and analysis of historical data, primary focus is placed on experimental methods of scientific investigation. Each course develops student skills and confidence in scientific investigations by presenting a progression of the four levels of inquiry (Banchi & Bell, 2008). The level of support from the teacher is gradually reduced, and the level of responsibility and creativity required of the students is slowly increased by guiding the students through the four levels shown in Table 1.1.

The first inquiry activities of the ninth grade year are Confirmation Inquiry activities related to the unit content, where the students are given the question and procedure for an activity with a known solution. These activities are used to allow the students to model and practice the scientific process, while at the same time

Table 1.1: The four levels of inquiry and the information given to the student in each level (Banchi & Bell, 2008).

Level	Question	Procedure	Solution
1—Confirmation Inquiry: Students confirm a principle through an activity when the results are known in advance.	✔	✔	✔
2—Structured Inquiry: Students investigate a teacher-presented question through a prescribed procedure.	✔	✔	
3—Guided Inquiry: Students investigate a teacher-presented question using student designed/ selected procedures.	✔		
4—Open Inquiry: Students investigate questions that are student formulated through student designed/selected procedures.			

helping students to master the scientific content, as well as laboratory equipment and experimental techniques. The importance of a strong knowledge base as a foundation for doing science is emphasized to students.

Gradually, as the year progresses, activities become Structured Inquiry, then Guided Inquiry, and then at the end of each semester, the students are asked to do an Independent Research Project, which is an Open Inquiry level activity. The students are required to independently identify a topic of investigation, define the research question, research the topic to ensure a mastery of the current knowledge on the topic, design and conduct an investigation and finally analyze and draw conclusions from the result. For an IRP, students are encouraged to ask original questions: questions to which no one knows the answer, not even the teacher. This ensures that the students are fully engaging in a complete, authentic scientific process of investigation, from problem finding to knowledge creation. This results in increased student engagement and motivation through maximizing their sense of ownership of the project (Ayar & Yalvac, 2010; Roth, 1995). Each year through high school, the proportion of the lower level inquiry activities is reduced, and the proportion of higher-level inquiry activities is increased, all the while maintaining a balance between content mastery and using that content to master the process of science through inquiry activities.

This series of investigations exposes students to, and helps them master, the skills needed to design, conduct, analyze, and report on independent, original investigations related to the content of the course. Students are supported in this with an on-line "Writing Guide" (Eales, 2009) that describes and explains the skills needed in scientific investigation and reporting, and offers exemplars for the students to use as models.

In grades 11 and 12, students at ISB enroll in two-year International Baccalaureate (IB) science courses. The International Baccalaureate Organization (IBO) prescribes the IB science curriculum, including content requirements and a number of hours to be spent doing practical laboratory investigations during which students are required to show competence in the design, conduct, analysis and presentation of scientific investigations.

Students in IB Physics courses that are part of the SRPP are regularly reminded to think in terms of the three-part model of the scientific process illustrated in Figure 1.1. They understand that the mastering of the course content is the necessary foundation for the next steps of creating new knowledge and publishing. They are made aware, and regularly reminded, of the *Journal of Science* and the opportunity to publish research that is of an acceptable standard. (The *Journal of Science* will be more fully described later.) Lab experiences in the course are scaffolded to continue to help students develop the skills needed to conduct scientific research. Students have access to a Writing Guide for the IB Science courses. The course lab experiences lead to a series of several IRP's, which must be grounded in course content. These IRP's are conducted in the latter part of the course. Before each IRP, students are reminded of the opportunity to publish if their work yields original, reliable, and valid results.

Students in SRPP-based courses develop the knowledge and skills needed to design, conduct, analyze, and report on original scientific research. They do this through mastering course content and experiencing an appropriately leveled, scaffolded series of laboratory investigations during the course progressing from guided-inquiry to open-inquiry. Students then demonstrate their ability to create and report on new scientific knowledge through the Independent Research Projects that they conduct in the course.

In 2007, the author realized that Physics students at ISB were regularly engaged in original, authentic scientific research, and that they were making valid scientific discoveries. Their work had to be classified as real scientific research, which has been described by Griffiths (2004) as:

> a systematic process of investigation—i.e. one that is carefully designed and executed with regard to relevant methodological principles. It is also expected to be aimed at advancing knowledge within the field of inquiry, and not just acquiring information that is new to the inquirer or needed for an immediate practical task. And it is expected that the findings and the methods are made public, so that their validity, and their contribution to the existing knowledge base, can be assessed by the wider community of experts in the field. (p. 714)

While the topics that students in SRPP courses were investigating were very simple, entry-level physics, their results *had to be* classified as new knowledge, since no one else had ever conducted and published research on their topics. They were creating new knowledge and, given that a crucial aspect of the success of the scientific endeavor is the publishing of new discoveries, as noted in Griffith's description, their discoveries could be published in a peer-reviewed scientific journal. Since there were no scientific journals in existence that would consider publishing the simple discoveries of our high school physics students, the author, along with a colleague, Dr. Ian Jacobs, founded the *ISB Journal of Physics* (Eales, 2007). The *Journal of Physics* was re-named as the *Journal of Science* (*JoS*) in 2012 in anticipation of expanding into other sciences.

The *ISB Journal of Science* is an on-line, entry-level, peer-reviewed scientific journal dedicated to publishing the original research of ISB students. The *Journal* is a registered publication with ISSN 2286-8038 and was accepted for listing on the Directory of Open Access Journals in 2011 (DOAJ, 2014). The *Journal* is published on an annual basis, with papers published on a rolling basis as they are completed.

At the time of writing, the *ISB Journal of Science* was one of a very few secondary school based peer-reviewed scientific journals in the world. Only a few journals have been identified which publish peer-reviewed original research by secondary school students, (Broad Street Scientific, 2014; NHSJS, 2014, JEI, 2014). But these mostly publish the work of students who are mentored by university professors and conduct their research in university labs. The *ISB Journal of Science* is, as far as the author can determine, the only journal in the world that publishes entry-level work done independently by secondary students as part of their normal science courses.

Publishing a paper is an opportunity that is presented to all students. It is not a part of the course or required in any way. Students write and edit the paper outside of class time and receive no class credit for publishing. Typically, about 15-25 % of students publish a paper during the two years of their SRPP-based IB Physics course. The following describes the process by which student research is selected and externally reviewed, and the paper is written, revised and published.

After students have completed an IRP in a course, the teacher reviews the lab reports submitted by the students and selects any which fit the publishing criteria. The criteria for publishing in the *JoS* are as follows:

Originality The research must be original. It must not be a repeat of a well-known principle or an investigation that yields a trivial, predictable result.

Validity The results must lead to a valid conclusion. The results must show a clear trend that fits applicable theory, if any.

Confidence The uncertainties in the results are small, giving the conclusions a reasonably high level of confidence.

Continuity The research suggests further areas of worthwhile investigation.

Importance The work does not need to be particularly important, as long as it adds a small piece of valid and reliable knowledge to the current human store.

Once the teacher has selected potential IRP's for publishing, the teacher consults with the authors of the IRP's to ensure that they have the desire, ability, and time needed to publish their work. After the teacher has completed the IRP selection process, the IRP reports are forwarded to the Editor of the *Journal*.

The Editor reviews the selected IRP's to ensure that they meet the criteria and then forwards the IRP reports to appropriate external reviewers. The reviewer looks at each IRP and determines whether the work matches the criteria for publishing. It is important that the Reviewer not know the identity of the authors, to ensure impartiality. The Reviewer sends the submitted IRP's back to the Editor with an explanation of the decision on each.

It should be noted that the external review process is crucial to ensuring the accuracy and validity of the published work. Without a strict review process, the *Journal* would be nothing more than a place to post student work.

Once an IRP has been approved for publishing, the teacher works with the student authors, in consultation with the Editor, to write and revise the paper. Given that the style for scientific papers is very different from that for school lab reports, students are provided with exemplars to help them write the paper. The writing and revising process typically takes three to four drafts before a final paper is produced.

The final draft of the paper is submitted to the Reviewer for approval. The Reviewer may approve the paper for publication or suggest modifications. After addressing the Reviewer's suggestions, as necessary, the paper is published in the current issue of the *Journal*.

To summarize, the SRPP is embedded in the standard, inquiry-based science curriculum followed at ISB. The SRPP courses focus students on mastering the scientific process illustrated in Figure 1.1. Students are required to complete authentic, original research in the course with the goal of publishing their work. Student research is submitted to the entry-level scientific journal, the ISB Journal of Science, where it undergoes an academic peer-review process. Students whose research is accepted for publication are mentored through a writing and revising process to enable them to gain the skills necessary to produce a publishable scientific paper. The conditions experienced by students in the standard ISB science program is compared to the conditions experienced by students in the SRPP in Table 1.2 on the following page.

Table 1.2: Summary of conditions and experiences of students in the SRPP and students in the standard ISB science program.

Conditions and Experiences of the Students in the Standard Science Program and those in the SRPP	**Group**	
	Standard	**SRPP**
Standard ISB Grade 9 & 10 Science Program:	□	□
• Content in Physics, Chemistry and Biology typical of North American curricula (120 hrs/yr)	□	□
• Inquiry-Based Practical Laboratory program leading students from Confirmation Inquiry to Open Inquiry	□	□
• Required Independent Research Projects	□	□
• Emphasis on student writing and reporting skills with online ISB Science Writing Guide as supporting resource	□	□
Standard IB Physics Course:	□	□
• Duration: Two Years, Grades 11 and 12 (240 hrs total)	□	□
• Course curriculum content prescribed by the IB (180 hrs)	□	□
• Practical Laboratory program with required criteria and demonstrated skills prescribed by IB (60 hours)	□	□
• External Assessment of Content by IB	□	□
• Internal Assessment of Practical Laboratory IB-required criteria and skills by teacher	□	□
Student Research and Publishing Program:		□
• Duration: Two Years (Gr. 11 & 12) – Integrated into IB Physics Course as part of required 60 hr IB Lab Program		□
• Initial Introduction and continued, regular emphasis of simplified 3-part SRPP model of the Process of Science (Figure 1.3) as focusing structure of course		□
• Initial Introduction and continued, regular emphasis of the entry-level *Journal of Science* and the possibility of publishing research findings as a paper in the *Journal*		□
• Required authentic, original, scientific research investigations (3-4 projects during the 2-year course)		□
• Support provided in selecting and refining authentic, original research topics		□
• Emphasis on authentic scientific writing and reporting skills with online ISB IB Science Writing Guide as supporting resource		□
• Opportunity to submit research for peer-review and selection process		□
• Mentoring during process of writing, revising and publishing a scientific paper in an entry-level journal for selected students (Time outside of class)		□

Statement of the Problem

Enabling secondary school science students to experience and understand an authentic process of science has been, and continues to be, an elusive goal. Too often, our science courses do little more than convey a body of information to our students. In 1910, Dewey complained that "Science has been taught too much as an accumulation of ready-made materials with which students are to be made familiar, not enough as a method of thinking, an attitude of mind." (Dewey, 1910, p.122). After a century of effort, science classes still do not reflect authentic science. Very few science classes teach students genuine inquiry (Chinn & Malhotra, 2002). And courses that do teach the 'scientific method' portray an overly simplistic and unrealistic picture of the true process of science (Krajcik & Merritt, 2012).

While efforts have been made to develop a more accurate understanding of the scientific process (Harwood, 2004), the author believes these are too complex to be useful in helping secondary school science students approach mastery of the process of science . A related issue is that often those who advocate for inquiry based learning fail to understand the need for keeping the balance between mastering course content and developing inquiry skills. Both are required for a genuine experience of the scientific process (Roth, 1995; Edelson, 1998; Chiappetta & Adams, 2004).

Finally, students in secondary school science courses rarely have the opportunity to experience the process of engaging in original scientific research and publishing their findings. Some programs like this exist at the undergraduate level, and these have been shown to be effective in helping students experience and understand an authentic scientific process (Dempster, 2003; Wink &Weaver, 2009; Russel, 2010; Weston, 2012b). But it is difficult to find a program in secondary school science in which students experience a complete and authentic scientific process leading up to and including conducting original scientific research and publishing their findings.

The author of this study strongly believes that this is a problem that can be solved. The Students Research and Publishing Program currently established at ISB addresses both the issue of independent research and of publishing that work. But the question remains: Is the program successful in helping students experience and understand an authentic scientific process, and what are the effects of the program on students' learning outcomes? A further question is: Is it possible to implement the SRPP at other schools, and if so, what are the conditions and processes required for successful implementation of the program?

The aim of this research is evaluate the effects of the SRPP on student outcomes to demonstrate the benefits and limitations of the program. Having established the benefits and limitations of the program, a Model for Implementation of the SRPP will be developed to aid other schools interested in adopting the program.

Studying the related literature, presented in the following chapter, has shown that participating in authentic scientific processes affects four major areas of student outcomes: science-related attitudes, understanding of the nature of science, research and publishing skills and attitudes, and 21^{st} century skills. These four areas will be studied in this work.

Once the effects of the SRPP in these four areas have been studied, and the benefits and limitations of the SRPP have been established, it is expected that other schools might be interested in establishing the SRPP at their own school. It would be helpful for them to know the conditions needed and the process to follow to successfully establish the Program in another school. Therefore, the final aim of this work will be developing a Model for Implementation of the Student Research and Publishing Program in other schools.

Research Questions

1. What are the effects of the Student Research and Publishing Program on students' science-related attitudes?

2. What are the effects of the Student Research and Publishing Program on students' understanding of the Nature of Science?

3. What are the effects of the Student Research and Publishing Program on students' experimental research and publishing skills and attitudes?

4. What are the effects of the Student Research and Publishing Program on students' development of 21st Century Skills?

5. What are the conditions and processes required for successful introduction and implementation of the Student Research and Publishing Program in Secondary School Science?

Research Objectives

1. To determine the effect of the Student Research and Publishing Program on students' science-related attitudes.

2. To determine the effect of the Student Research and Publishing Program on students' understanding of the Nature of Science.

3. To determine the effect of the Student Research and Publishing Program on students' experimental research and publishing skills and attitudes.

4. To determine the effect of the Student Research and Publishing Program on students' development of 21^{st} Century Skills.

5. To develop a Model for Implementation of a Student Research and Publishing Program in Secondary School Science.

Research Hypotheses

1. The Student Research and Publishing Program will have a significant positive effect on students' science-related attitudes.

2. The Student Research and Publishing Program will have a significant positive effect on students' understanding of the Nature of Science.

3. The Student Research and Publishing Program will have a significant positive effect on students' experimental research and publishing skills and attitudes.

4. The Student Research and Publishing Program will have a significant positive effect on students' development of 21^{st} Century Skills.

Theoretical Framework

This research is grounded in three theoretical constructs: constructivism, inquiry-based learning, and the process of science. Each of these plays a part in the development of the SRPP and in its expected benefits. We will now briefly review the theory behind each of these aspects of the program.

Constructivism

Constructivism is a theory of learning that is derived from Piaget's "Stages of Learning". While Constructivism in education has evolved considerably, Piaget's ideas are foundational, and he is considered the 'father of constructivism' (Sjoberg, 2007). But what is constructivism exactly?

Douglas Llewellyn (2005) provides a clear and concise description of Constructivism. Llewellyn defines Constructivism as a theory about "how we come to know what we know" (p.28). Constructivism posits that new knowledge is constructed based on the context of current knowledge and experience. Learning is an active process in which the learner is constantly attempting to fit incoming information, concepts, and experiences into their existing structure of understanding. Learning is active, adaptive and evolutionary. Constructivism holds that "learning is self-regulating and socially mediated as the student actively engages, interacts, and operates within the confines of his or her environment" (Llewellyn, 2005, p.28).

Constructivism can be contrasted with learning theories such as behaviorism, which states that learning is a change in observable behavior in response to stimuli, or objectivism, which claims that all knowledge exists independently of the learner and that learning consists of imparting that knowledge to the learner (Skinner, 1950). Constructivism can be concisely described as holding that "learning is a process of integrating new knowledge with prior knowledge such that knowledge is continually constructed and reconstructed by the individual" (Hunter, Laursen & Seymour, 2007, p.38).

Inquiry-Based Learning

Inquiry-based learning (IBL) is a pedagogical theory that is based on constructivism. It is designed on the foundation of constructivist philosophy. The National Research Council (1996) of the United States in their National Science Education Standards describes IBL in science education as follows:

> When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills (p. 23).

IBL involves active student involvement in the learning process, as befits a constructivist philosophy of learning. It is important to note that even though IBL emphasizes "active learning," it is not necessarily about physically active learning. IBL emphasizes cognitively active learning (Mayer, 2004). As can be seen from the above quote, all aspects of Bloom's Taxonomy (Anderson & Krathwohl, 2001) are addressed in Inquiry learning. Students learn about "current scientific knowledge", "describe objects and events", "construct explanations", "test explanations", "use critical thinking", "consider alternative explanations", and "develop understanding, reasoning and thinking skills". Some scholars have misrepresented IBL as concerned only with process, not content, but a clear understanding of IBL theory shows that it is a theory that holds that all learning requires the active involvement of the learner in mastery of both content and process, as appropriate to the topic and the situation (Chiappetta & Adams, 2004).

Inquiry-based learning has also been clearly described by the National Science Foundation (NSF):

> Inquiry is an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making

> discoveries, and rigorously testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science (Foundations, 2004, p.2).

IBL, as can be seen from the quote above, is focused on active learner involvement in the process, as opposed to traditional lecture-based instruction, in which the student is a passive receiver of information. The NSF emphasizes the importance of IBL mirroring as closely as possible the real process of science, which, it should be pointed out, is the strength of the Student Research and Publishing Program currently in use at ISB: The opportunity to publish in an entry-level, peer-reviewed, scientific journal provides the students with the experience of authentically participating in the scientific enterprise. The *Journal* allows high school science students to not just "mirror as closely as possible the enterprise of doing real science", it lets them *be* real scientists, participating in the process of making new discoveries and publishing their findings in a scientific journal.

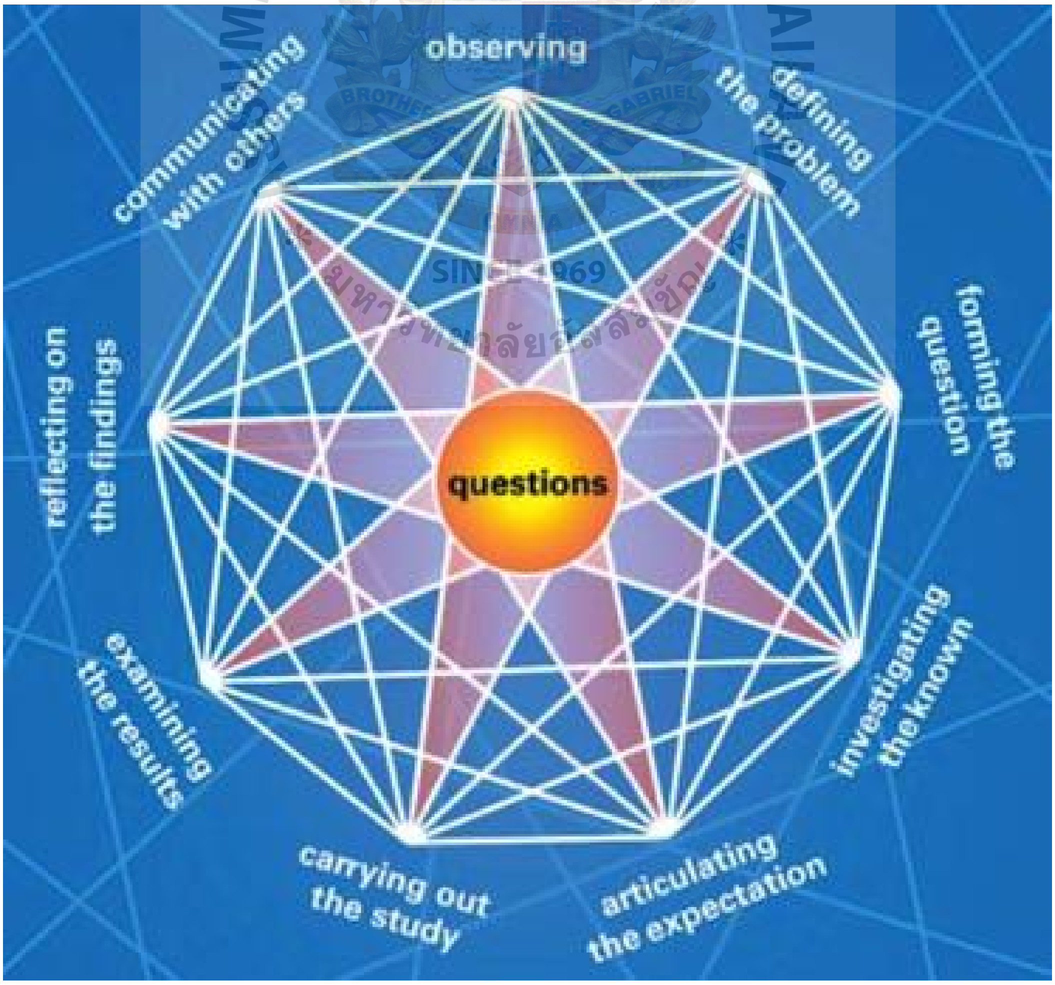
Process of Science

The process of science is complex. A scientist is an expert whose methods vary with each situation, making it difficult to define a single "process of science". However, some general attributes can be identified which characterize how scientists act.

While most schools teach their students the traditional "scientific method", with its rigid linear steps, it is clearly too simple a model to describe the complexity of the scientific process (Krajcik & Merritt, 2012). The Scientific Method, as traditionally taught, is also criticized as only describing one of the ways in which scientists learn, the hypothetico-deductive process, and ignores other important methods used by scientists, such as simulation models and statistical analysis of historical data (Reiff, 2004). As William Harwood (2004) and his team state: "Fundamentally, the scientific method model is too simple to describe the process of scientific inquiry that many scientists use. What we need, then, are some new models" (p.2). After conducting research on how scientists think and act, they developed a model of the scientific process of inquiry that better describes the variety and complexity of the processes experienced by scientists in their work. They call it the Inquiry Wheel, shown in Figure 1.2, below.

Rather than being a linear process, the Inquiry Wheel illustrates the variability and adaptability with which science is done. Given the central roles of "problem-finding" in science, the model places "questions" at the center of the wheel.

Figure 1.2: The Inquiry Wheel: a model of the scientific process (Harwood, 2004).

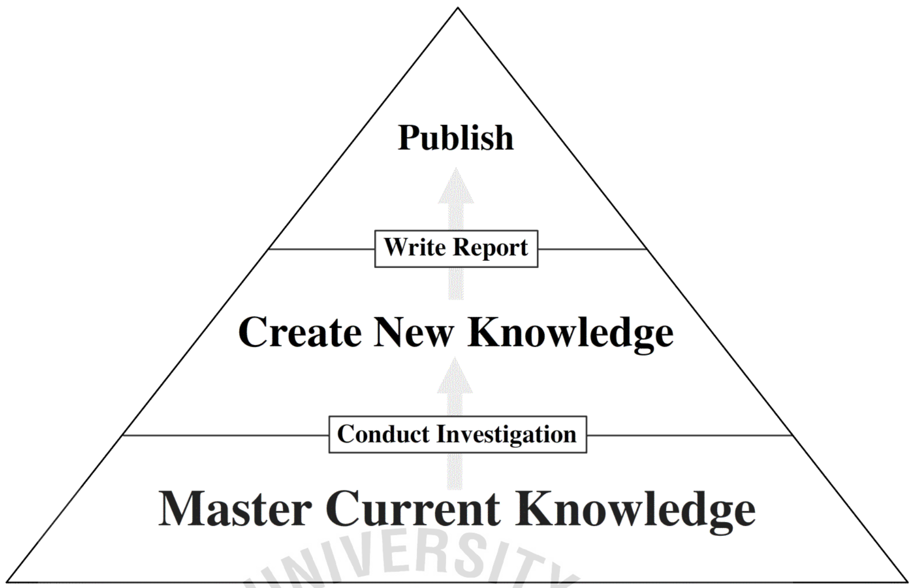


The model then places all the familiar processes of science around the rim of the wheel, with lines connecting each behavior to the central "questions" and to all the other processes. This shows that scientists do not have a particular and consistent series of steps through which they proceed, but rather will move from one process to another; forward, across, then back, then across, then back again, as needed, in any given investigation. The Inquiry Wheel identifies nine activities. "In the course of an inquiry, scientists move among these activities in unique paths and repeat activities as often as they find necessary" (Harwood, 2004, p.2).

While the Inquiry Wheel is useful in describing the process of scientific investigation practiced by expert scientists, the author has proposed another way of conceptualizing the process of science, termed the SRPP model of the process of science (Eales, 2014), which may be more helpful in secondary science education. This model is useful to both learner and teacher in providing a clear and simple framework for understanding the process of science in which the science learner is engaged. While it is agreed that the traditional "scientific method" taught in science class is inadequate (Krajcik & Merritt, 2012), the author contends that the inquiry wheel discussed above is overly complex and too focused on only the inquiry aspect of the scientific process, making it less useful for helping beginning science students to effectively conceptualize the process of science they are being asked to master.

The SRPP model incorporates all the steps in other models, but focuses emphasis on two aspects of the scientific process that are crucial and significant parts of the scientific process. These two parts, the author believes, are underemphasized, and thus often ignored, in other models used in secondary school science education. The SRPP model of the scientific process, previously shown in figure 1.1, is repeated here as Figure 1.3. It divides the scientific process into three parts: 1. Mastering

Figure 1.3: The simplified SRPP model of the scientific process (Eales, 2014).



current knowledge, 2. Creating new knowledge, and, 3. Publishing the newly created knowledge, with the processes of Conducting Investigations and Writing Reports acting as paths from one part to the next.

Most traditional models of the scientific process have focused almost exclusively on step two in this model: Creating new knowledge. This is the investigation process that is embodied in the traditional "scientific method" and is represented in seven out of nine activities identified on Harwood's Inquiry Wheel.

Scholars who have studied the role of expertise in science have shown that step 1, Mastering current knowledge, is crucial and foundational to the scientific process (Glaser & Chi, 1988; Roth, 1995). The author contends that this is especially true at the secondary school level, where students are still acquiring the skills of learning how to master current knowledge. Edelson (1998) states that "Effective science education will always consist of an appropriate balance between didactic instruction and hands-on activity. Meaningful science practice at any level requires an understanding of relevant fundamental science principles (p.17)." Yet "Mastering current knowledge" is under-emphasized in some current models of science education, with their emphasis on pure inquiry and concurrent denigration of content mastery through direct and guided instruction (Kirschner et al, 2006; Mayer, 2004). This proposed model better reflects the amount of time and effort which learners must invest in "Mastering current knowledge", before they can begin to resemble experts and can be successful in their continued practice of the process of science. Harwood's Inquiry Wheel makes "Mastering current knowledge" only one activity out of the nine, which is not representative of the reality of the requirements of the scientific process as practiced by expert scientists (Glaser & Chi, 1988).

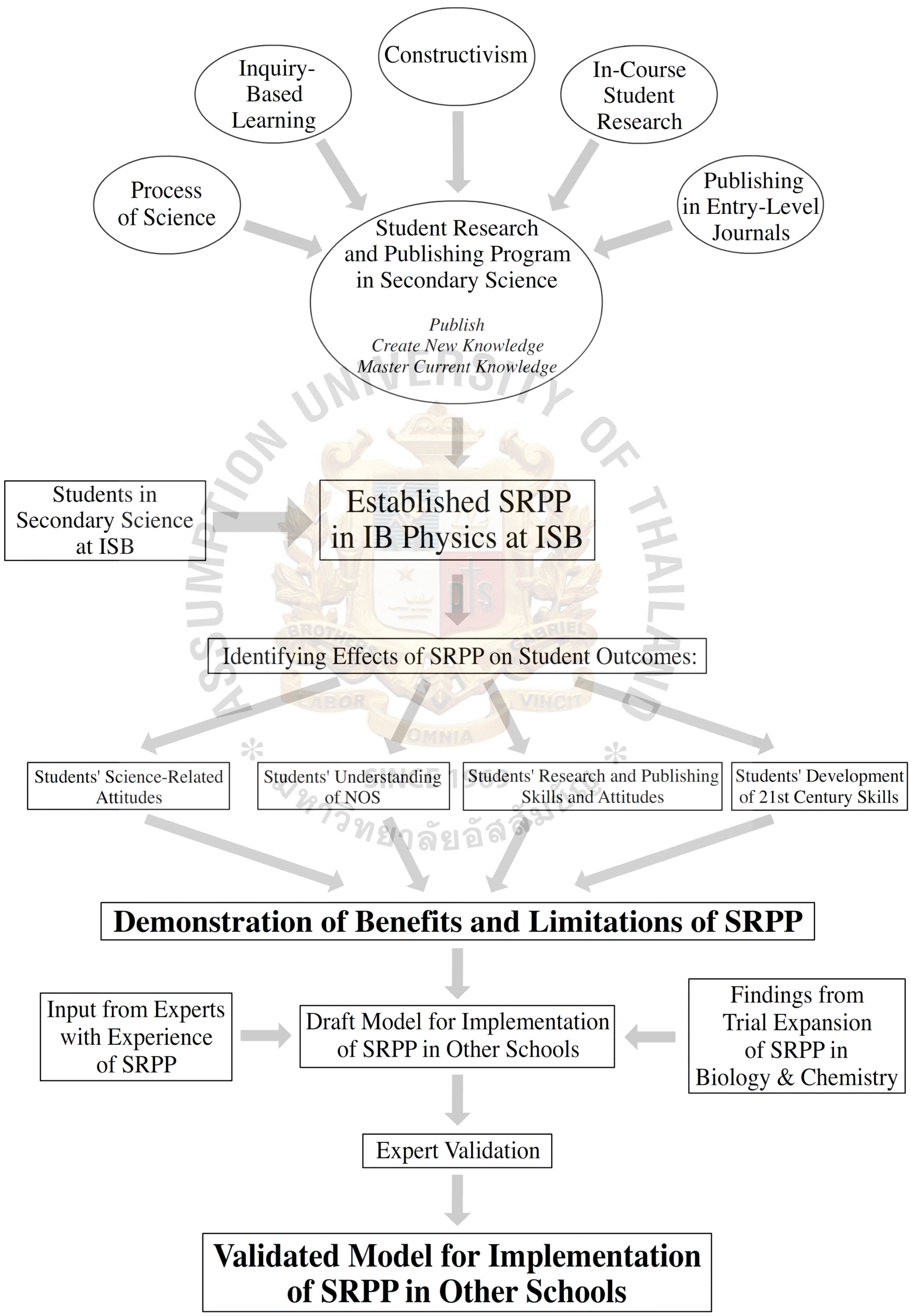
The third phase, "Publishing the newly created knowledge", is crucial to authentic scientific learning. Again, Edelson (1998) puts it well: "Science is not just investigation. It includes the sharing of results, concerns, and questions among a community of scientists (p.4)." The author contends that 'publishing the newly created knowledge' is under-emphasized in other models of the scientific process. Harwood's Inquiry Wheel again devotes only one of nine aspects on his wheel to this crucial phase of the scientific process. By making the publishing aspect of the process of science a separate phase in the conceptual model of the process of science used in secondary science courses, proper emphasis in time and effort can be focused on it. The task of communicating scientific findings is hugely complex and difficult for young learners, requiring significant higher-order thinking skills, organization and clarity of thought, clear and concise writing, and skilled presentation. Mastery of this process requires significant time and effort on the part of both the learner and the teacher. Making this one of the three phases places appropriate emphasis on this aspect, ensuring that necessary levels of time and effort are allotted to it.

The author believes that the SRPP model of the process of science, with only three parts, is simple enough to be easily understood and remembered, and usefully applied in the secondary science classroom. It places appropriate emphasis on the main aspects of learning to do science, leading to an allotment of time and effort that is appropriate to the learning of science in the classroom. Used in conjunction with a more traditional model such as the Inquiry Wheel, which mostly elaborates the details of step two in the SRPP model, it can be a powerful and effective tool in increasing student understanding and mastery of the process of science.

Conceptual Framework

The conceptual framework of this study is represented in figure 1.4.

Figure 1.4: The conceptual framework of the study.



Scope of the Study

This research aims to study the effects of the Student Research and Publishing Program in Secondary School Science currently implemented at International School Bangkok on four aspects of student learning. The research also aims to develop a Model for Implementation of the Program at other secondary schools.

A mixed methods approach will be used to study the four aspects of the effects of the SRPP on students learning. This will be done by comparing the skills and attitudes of ISB students in the graduating classes of 2010 through 2014 who were in Physics courses that included the SRPP with ISB students who were in Physics courses that did not include the SRPP. The four areas of student effect that will be included in the study are student science-related attitudes, student understanding of the Nature of Science, student experimental research and publishing skills and attitudes, and student development of 21^{st} Century Skills.

A mixed methods approach will again be used for the fifth research objective to investigate the conditions needed, and the challenges and benefits of implementation of the SRPP in other schools. This objective will be approached in two ways.

Firstly, students involved in a Trial Expansion of the SRPP conducted in the IB Biology and Chemistry classes for students in the graduating class of 2014 will be compared to IB Biology and Chemistry students in the graduating class of 2013, who were not involved in the Trial Expansion. The four areas of student effect will be studied, as described above. The teachers involved in the Trial Expansion will also be interviewed to gain insight into the conditions and processes required for successful introduction and implementation of the SRPP.

Secondly, the study will include a sample of students, teachers and administrators involved in the established SRPP. This sample will be interviewed to gain insight into their perceptions of the conditions and processes required for successful introduction and implementation of the SRPP in another school.

A Model for Implementation of the SRPP will then be developed which may be used to aid in the implementation of the Program in another secondary school's science program. The Model for Implementation will address the conditions and requirements needed by a school for successful implementation, as well as a detailed description of the process of preparing the school and then launching and establishing a Student Research and Publishing Program in the science program at the school.

Definition of Terms

Student Research and Publishing Program (SRPP) – refers to the program being studied in this research. It consists of an inquiry-based learning approach in which students are scaffolded as they progress through the four levels of inquiry to culminate in authentic, original research. The students' goal is to publish their original findings in an entry-level, peer-reviewed scientific journal. The SRPP uses a simplified model of the scientific process to place emphasis on three aspects of the process of science. These three aspects are defined as

1. Mastering current knowledge,
2. Creating new knowledge, and
3. Publishing the new knowledge.

Mastering Current Knowledge – An important part of becoming an expert is being a master of the content of the field. An important foundational task of science students is to master the current knowledge in the topic of study. This includes the relevant informational content, skills, and key understandings related to the topic that is currently known by scientists.

Creating New Knowledge – This refers to the original research that is conducted by students in the SRPP. This process models the goal of science, which is to discover new information and understandings of the world. This is often described as Open Inquiry, which is the culmination of the Inquiry process that students are taught during the SRPP. Creating New Knowledge is a complex, and difficult to define, set of skills and processes that play a central role in the process of science as a whole. Harwoood's (2004) Inquiry Wheel (Figure 1.2) devotes seven of the nine activities to what is defined here as the process of Creating New Knowledge.

Publishing New Knowledge – This refers to the process of students' submitting a paper presenting the results of original research to a school-based, entry-level, peer-reviewed, scientific journal such as the *ISB Journal of Science*.

Inquiry – Defined as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1996, p.23). In science learning, four levels of inquiry have been identified, from simplistic Confirmation Inquiry up to the most complex Open Inquiry (Banchi & Bell, 2008).

Authentic Science – Refers to learning activities in science courses which contain the essential characteristics of science as practiced by scientists, including their attitudes, methods, and social interactions (Edelson, 1998)

Original Research – Defined as an Inquiry-Based Learning activity in which the problem-question is created and defined by the students, the investigation is designed and conducted independently, and the outcome is unknown prior to the investigation. The findings of original research are expected to add to the body of current knowledge.

Scaffolding – Support for students provided by the teacher that is adjusted to the level required by the individual to enable success. The level of support is continuously reduced as the learner progresses, allowing the learner to grow in independence.

Process of Science (POS) – Refers to the behaviors, assumptions and attitudes of scientists in their work. While these are complex and difficult to define, POS in this paper will refer to the three-part model of science (Figure 1.3), with further details of the details, complexity, and non-linearity of the process being illustrated by Harmon (2004) in Figure 1.2. The process of science will be discussed more fully in Chapter 2.

Science-Related Attitudes – Students' Science-Related Attitudes is defined here as attitudes that students have towards science and its relationship to individuals and society, as measured by the Test of Science-Related Attitudes (TOSRA) survey instrument. The attitudes addressed include the Social Implications of Science, Normality of Scientists, Attitude to Scientific Inquiry, Adoption of Scientific Attitudes, Enjoyment of Science Lessons, Leisure Interest in Science, and Career Interest in Science. These will be discussed more fully in Chapter 3.

Nature of Science (NOS) – Nature of Science refers to aspects of science including its tentativeness, creativity, empirical basis, subjectivity, the variety of its methods and the development and nature of it theories (Liang et al, 2006). The nature of science will be discussed more fully in Chapter 2.

Experimental Research and Publishing Skills and Attitudes – This refers to the collection of skills and attitudes related to students' ability to design and conduct original scientific research and to publish their work in a Journal. The skills and attitudes related to research and publishing are complex, subtle, and numerous. For this research, the skills and attitudes that will be included are those measured by the Secondary Student Research Skills Self-Assessment (SSRSSA) survey instrument and the Attitudes toward and Effects of Student Publishing (AESP) survey instrument. Some of the more important aspects that will be addressed include understanding theory, experimental design, equipment use, data analysis and presentation, drawing conclusions, scientific writing, and presentation of findings, along with attitudes toward scientific research and desire and motivation to participate in the scientific community. This concept will be discussed more fully in Chapter 3.

21st Century Skills – A set of higher-level attitudes and skills identified as essential for success in the modern workplace. The aspects of 21st Century Skills that will be addressed in this study include creativity, innovation, problem-solving, critical thinking, communication, collaboration, information literacy, ICT Literacy, and flexibility, initiative, and independence (Trilling & Fadel, 2009). This term is discussed more fully in Chapter 2.

Semesters of University when Surveyed – This term is used in this study to quantify one of the variables that may have an effect on the dependent variables of the study. Therefore, the need to use this variable as a covariate in the analysis had to be considered. It will be used in the analysis of the results, and referred to in Chapters 3, 4, and 5. The survey instruments used in the study were administered to participants, in phases, between April 2013 and May 2014. Students in the graduating classes of 2013 and 2014 completed the surveys while still enrolled at ISB, thus being assigned a value of 0 for this variable. Students in the graduating classes of 2010, 2011, and 2012 conducted the survey after having completed 7, 5 and 3 semesters of university, respectively, thus being assigned values 7, 5, and 3 for this variable.

Science and Math Coefficient – This term refers to a variable that was calculated in an attempt to quantify a student's affinity for and ability in science and math. It was expected that a student's affinity for and ability in science and math might be correlated with some or all of the dependent variables studied. Therefore the need to use this variable as a covariate in the analysis had to be considered. The value assigned to the Science and Math Coefficient was derived from the students' science and math courses taken and grades earned during grade 12. It was calculated by summing the product of the course difficulty level and the grade earned for all the science and math courses taken by the student. For example, a student taking IB HL Physics (Difficulty Level Rating = 2), earning a B (Grade point = 3.0) and also taking IB SL Math (Difficulty Level Rating = 1), earning an A (Grade point = 4.0) would be assigned a Science and Math Coefficient of 10.0 (or [2×3.0] + [1×4.0] = 6.0 + 4.0 = 10.0). Students taking two HL sciences and math, and earning high grades, would have a high Coefficient, while students doing poorly in lower level science and math courses would score a low Coefficient. The Science and Math Coefficient is assumed to be a measure of a student's affinity for and ability in science.

Significance of the Study

Given the strength and importance of the benefits of student involvement in original scientific research and publishing that has been shown by researchers, (Bransford et al, 2000; Chinn & Malhotra, 2002; Dempster, 2003; Gengarelly & Abrams, 2009; Jungck, 2004; LaBanca, 2008; Roach et al, 2001; Roberts & Wassersug, 2008; Steward, 2007), it is imperative to our students' futures that we make every effort to incorporate these activities into their education as early as possible. In the current world of education, most science students do not experience original scientific research until late in university.

Programs allowing university undergraduates to participate in authentic scientific research with opportunities to publish their work do exist, and much research has been conducted into the benefits of these programs (Wink & Weaver, 2009; Russell, 2010; Roach et al, 2001; Dempster, 2003; Seymour et al, 2004; Gutterman, 2007, Burns & Ware, 2008). But while there are a few programs which allow secondary students to participate in conducting and publishing authentic scientific research (Roberts & Wassersug, 2008; Le, 2010; Broad Street Scientific, 2014; NHSJS, 2014), there is, as far as the author is aware, no published research studying the effects on secondary students of participating in authentic, original scientific research and publishing the results of their work in peer-reviewed scientific journals. Nor is there any published research developing a Model for Implementation of such a program, to aid other schools in starting a program such as this.

We do not currently know what the effects of these programs are at the secondary school level, or what the conditions and limitations are for implementation, or the best practices for implementing these programs in new schools. Creating this knowledge is the goal of the current research.

If it can be shown that the Student Research and Publishing Program in Secondary School Science, with its opportunities for student research and publishing in the *ISB Journal of Science*, provides significant benefits to student learning in important areas, and a Model for Implementation can be developed to guide the implementation of this program in other secondary schools, then a significant contribution to our understanding of science education, and to improving the science education of secondary students, will have been made.

CHAPTER II

REVIEW OF RELATED LITERATURE

There is much work that has been done in areas related to the proposed research. This chapter will begin with an overview of the literature on the three theoretical aspects of the research: Constructivism, Inquiry-based learning, and the nature of science. Then literature related to authentic learning, research-based learning, undergraduate scientific journals, and 21st century skills will be reviewed. It is hoped that with a review of related literature, a clearer picture of the SRPP, with its potential benefits and limitations, and its required conditions and implementation challenges, will emerge.

Constructivism

Constructivism, as has been mentioned earlier, is a theory of learning in which new knowledge is constructed based on the context of current knowledge and experience. Learning is an active process in which the student is constantly attempting to fit incoming information, concepts, and experiences into their existing structure of understanding. Learning is active, adaptive and evolutionary (Llewellyn, 2005). Constructivism, as stated earlier, is derived from Piaget's "Stages of Learning", and he is considered as the 'father' of constructivism (Sjoberg, 2007). Constructivism is used as the theoretical foundation for inquiry-based learning, the dominant paradigm in modern science education, as evidenced by the fact that it is espoused in science learning standards published worldwide (AASL, 2009; Hodge, 2007; NRC,2012; Rajagopalan et al, 2004; NGSS Lead States, 2013).

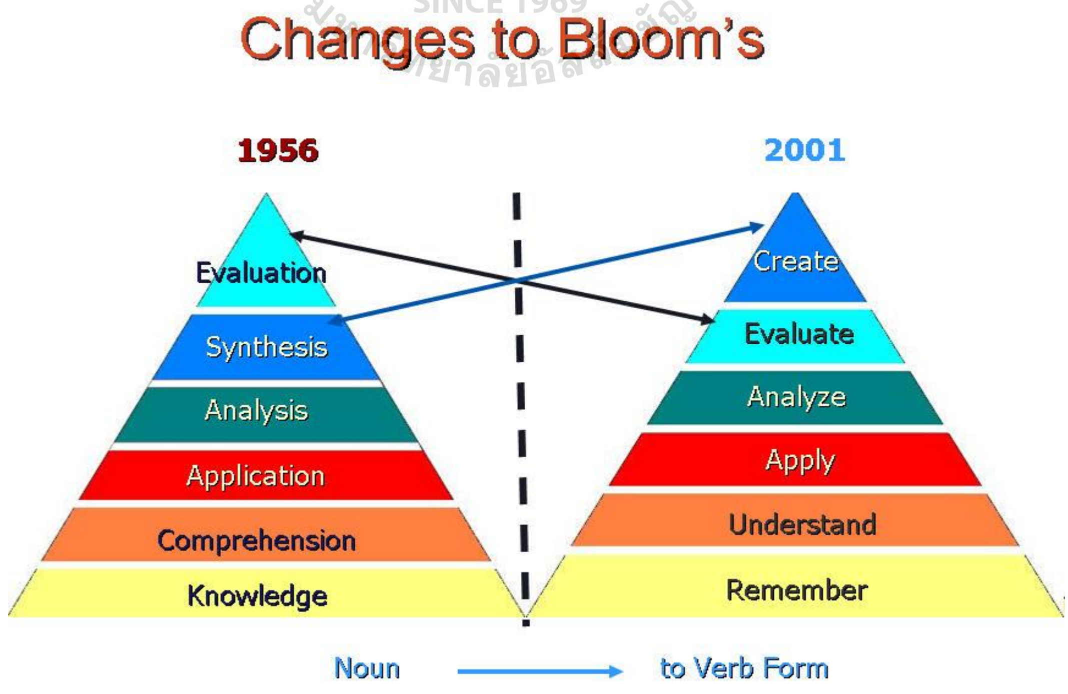
While constructivism is the dominant paradigm, there are other learning theories that should be recognized. Historically, behaviorism was one of the first formally defined learning theories used to support pedagogical design. Behaviorism is a learning theory based on empiricism (Skinner, 1950). It holds that learning is a process of forming connections between stimuli and response. By the middle of the last century, the limitations of behaviorism and its applicability to human learning became apparent (Bransford et al, 2000).

A learning theory that is related to constructivism is social constructivism, derived from the work of L.S. Vygotsky, a psychologist in the early 1900's. While constructivism focuses on the learning process within the individual's mind, social constructivism holds that the learning takes place within the process of social interaction between learners. Social constructivists therefore place great emphasis on group work, ensuring that all learning activities focus on the social interactions of the learners (McKenzie, 1996).

In recent years, some scholars have challenged the validity of constructivist theory in education. They argue that a new theory of learning is needed if we are to succeed in education. Roland Schulz (2009) points out that education has traditionally appropriated theories developed in other fields as the basis for developing learning theories. He argues for the development of a philosophy of education from within the field of education, which will more closely fit the situation. Schultz calls for a new theory of learning based on Kieran Egan's (2005) cultural-linguistic theory. Mary Kalantzis and Bill Cope, again building on Vygotsky, call for a New Learning theory to meet the changing demands of the new century (Kalantzis & Cope, 2004). This New Learning needs to fundamentally rethink the nature of pedagogy. It needs to be creative, and be "systemic, rhetorical, and evident in the everyday practices of teaching and learning" (Kalantzis, 2006, p.7). They have proposed a "Learning by Design" theory of learning that is grounded epistemologically, rather than psychologically (like constructivism). They ground their proposed theory in "what we do to know", focusing on the acts that learners perform as they experience, conceptualize, and analyze while learning, rather than focusing on the inner workings of the mind, which they claim are too difficult to determine and understand.

While Bloom's Taxonomy (Bloom & Krathwohl, 1956) is not really a Theory of Learning in the true sense, the SRPP's emphasis on higher-order thinking skills makes it important to briefly review it. A recently published consideration of Bloom's Taxonomy, illustrated in Figure 2.1, has proposed a modification to the traditional pyramid, in light of recent movement in pedagogical theory.

Figure 2.1 Bloom's Taxonomy revised. Note the significant change at the top of the pyramid (Anderson & Krathwohl, 2001).



Anderson and Krathwohl (2001) propose a "Taxonomy for Learning." They have changed the form of each of the levels from a noun to a verb, with the intent to describe the action of the learner, rather than the product of the mind (note the parallels with Kalantzis and Cope above). The most significant change they propose is at the top of the pyramid, where they change "synthesis" to "create" and move it to the top of the pyramid. This change reflects the new ways we learn and new competencies we must possess in our 21st century world. These will be discussed further below.

While it is worthwhile to be aware of the issues and limitations of constructivism, and of proposals for new theories of learning, the fact that the SRPP being studied in this research uses inquiry-based learning methods, which are based on constructivism, means that we will, along with a large number of current educational researchers, accept its validity as a theory of learning.

Inquiry-Based Learning

As it is the basis of the methods for teaching science at ISB, we must review the research literature on inquiry-based learning. We will here focus on research studying the benefits and issues of implementing inquiry-based learning in science education, since the definition and practice of inquiry-based learning were discussed in detail in Chapter 1.

Inquiry-Based Versus Traditional Learning

Douglas Llewellyn, in his book, *Teaching High School Science Through Inquiry*, describes the differences between inquiry-based learning and traditional learning. He describes a traditional classroom as "teacher-centered", with "teacher-talk" taking up most of the available time as the teacher delivers content and skills to the students. While there is usually time for students to demonstrate understandings and practice skills, it is at the direction of the teacher (Llewellyn, 2005, p. 55). Inquiry-based classrooms are quite different. Inquiry-based learning (IBL) classrooms are usually described as student-centered. Students have an attitude of inquisitiveness, with an active involvement in activities (Llewellyn, 2005, p. 56). Students engage in self-generated investigations that cause them to reflect on and take responsibility for their individual learning. In short, students act as researchers: working in groups, utilizing higher-order thinking skills, and showing interest in science (Llewellyn, 2005, p. 58).

A large number of studies have been done comparing inquiry-based and traditional learning. Here we will highlight a few of the most instructive cases. Joel Bryant (2006) had been a typical teacher who was unconvinced of the effectiveness of IBL and concerned with the extra time required to cover content in an IBL classroom. To put IBL to the test, he conducted a study comparing traditional and unguided inquiry-based physics laboratory investigations for pre-service elementary science teachers. He found that students doing the unguided inquiry investigation demonstrated superior mastery of both knowledge and understanding of physics concepts, when compared to those who experienced the traditional lab activity.

Robert Geier and his team (2008) investigated the effect of IBL on urban students in the US. They found that students experiencing IBL achieved improved results on standardized tests. Not only that, he found that the gains increase with increased exposure to IBL. Geier et al's results show that "the more inquiry science instruction we are able to provide to students during their schooling, the larger the learning growth we will expect to see in achievement" (Geier et al, 2008, p.934), a finding that has been confirmed by others. It has also been shown that IBL has a significant impact on content mastery, student attitude and interest in science, and self-efficacy (Fencl & Scheel, 2005; Trumper, 2006; Tsai & Tuan, 2005; Wolf & Fraser, 2008).

Authentic Inquiry

Many researchers have investigated the importance of the level of inquiry in which students engage. Four levels of inquiry have been identified, from confirmation inquiry to open inquiry, as previously described in Table 1.1 (Banchi & Bell, 2008), with rubrics developed to identify the levels of any activity being studied (Fay, Grove, Towns & Lowery 2007). Much research has been conducted on the effects of the different levels of inquiry on student outcomes, with many advocating what is termed authentic science learning. But before we can look more deeply at the effects of authentic science learning, we need to describe what we mean by this term.

Wang, Dyehouse, Weber & Strobel (2012) surveyed the literature on authentic science learning in order to help educators form a clear understanding of what it means, and what it looks like in practice. They identified four aspects of authenticity that are present in authentic science learning: Context Authenticity, Task Authenticity, Impact Authenticity, and Personal/Value Authenticity. They go on to identify a number of factors and characteristics that are important features of authentic science learning, as shown in Table 2.1 on the following page.

It should be noted that the SRPP exhibits many of the features of authenticity described by Wang et al (2012). The process of students conducting original research with the goal of publishing their findings in the *Journal of Science* is

Table 2.1: Factors of Authenticity in Science Learning. (Wang et al, 2012).

Key factors of authentic problems	**Key outcomes of authentic problems/ situations**
1. Real-world context/ Future professional situation 2. Complete task-environments 3. Ill-structured, non contrived problems with ambiguous data 4. Suspension of disbelief 5. Interaction among learners 6. Decision-making in practical contexts 7. Value beyond school 8. Values defensible in objective terms 9. Provide information/ data that is from or mimics real-life or skills 10. Classroom-professional community balance 11. Complex problem transcending the borders defined by disciplines	1. Promote disciplined inquiry 2. Active self-knowledge construction 3. Higher-ordering thinking 4. Self-exploration 5. Openness/ diversity of forming the problem, solving the problem, and outcomes 6. Personal interest, school goal and professional goal combination 7. Students' interest, belief, and value

clearly an authentic science learning process. All four aspects: Context, Task, Impact, and Personal/Value, are present in the learning processes of the SRPP, as are most of the factors and outcomes enumerated in Table 2.1.

Edelson (1998) looked at the process of adapting authentic science practice to the learning environment. He identified three elements of authentic scientific inquiry which had to be addressed when developing authentic science learning: attitudes, tools and techniques, and social interaction. Edelson contends that much of current practice that claims to be authentic focuses solely on the tools and techniques of authentic science practice. He argues that students must also learn the attitudes of uncertainty and committment, which can only happen when students "have the opportunity to adopt questions that represent true uncertainty in their world. To foster commitment among students, the questions they pursue must have ramifications that are meaningful within the value systems of these students. (p.3)" And, Edelson argues, students must also experience the social interactions of scientists as they share their questions, findings, and conclusions with other scientists.

While Edelson does not directly advocate student-published scientific journals, it is clear that the SRPP addresses all three aspects of authentic science practice as identified by him.

Another influential researcher in the field of authentic inquiry is Wolf-Michael Roth (1995) of the Netherlands. While the following quote is extensive, it is included in full, as it speaks directly to the focus of the SRPP. Roth states that:

> School activities, to be authentic, need to share key features with those worlds about which they teach. More specifically, for school science to be authentic, students should experience scientific inquiry which bears at least five aspects in common with scientists' activities: (1) participants learn in contexts constituted in part by ill-defined problems; (2) participants experience uncertainties, ambiguities, and the social nature of scientific work and knowledge; (3) participants' learning (curriculum) is predicated on, and driven by, their current knowledge state (wherever that might be); (4) participants experience themselves as part of communities of inquiry in which knowledge, practices, resources, and discourses are shared; and (5) in these communities, members can draw on the expertise of more knowledgeable others whether they are peers, advisors, or teachers. Both "open-inquiry" and "authentic" imply these five aspects of our learning environment which it shares with the scientific community.
>
> Specifically and more practically, open inquiry implies that students (a) identify problems and solutions, and test these solutions, (b) design their own procedures and data analyses, (c) formulate new questions based on their previous claims and solutions, (d) develop questions based on their prior knowledge, (e) link their experience to activities, science concepts, and science principles, and (f) share and discuss procedures, products, and solutions. (p.2)

Roth is very clear in his advocacy of the need for students to engage in open-inquiry activities which model the scientific process authentically. Donovan and Bransford, in their book, *How Students Learn*, support this position. They argue for the importance of ensuring that students “experience the processes of inquiry (including hypothesis generation, modeling, tool use, and social collaboration) that are key elements of the culture of science” (Donovan & Bransford, 2005, p. 398), while Aitken and Pungur (2005) point out that “Authentic tasks help students rehearse for the complex ambiguities of adult and professional life. (p.1)”

Buxton (2006) surveyed typical practices in science classrooms, and categorized authentic science learning into three categories: the canonical perspective, the youth-centered perspective, and the contextual perspective. The canonical perspective focuses on authenticity as mirroring the work of scientific laboratory investigations. The youth-centered perspective is usually set outside the classroom, and focuses on allowing students to choose topics to investigate based on personal interest and relevance. The contextual perspective is a combination of the first two, wherein students are allowed to choose topics, based on personal interest, that are then investigated in the lab with attention to mirroring authentic laboratory practice. The SRPP clearly is a model of the contextual perspective of authentic science learning.

Ayar and Yalvac (2010) also studied the practice of authentic inquiry in the classroom. They found, similarly to Edelson, that much of current practice focuses solely on the investigation aspects of the scientific process. They argue that this leads to a flawed understanding of the nature of science on the part of the learner. They believe that consideration must be given to the sociological characteristics of the scientific process when designing authentic science learning programs.

> Students should be given the opportunities to participate in authentic learning environments where they will engage in real scientific practice because they have been repeatedly told that scientific concepts can be learned through reading science textbooks or listening to their science teachers, which in turn led them to formulate naïve understandings of science and its enterprise. The concepts of uncertainty, commitment, mutual engagement, shared repertoire, and collaboration in scientific practice should be exposed to every citizen so that the people will not view science as a body of knowledge explaining the physical phenomenon, but a social human activity that is parsimonious and social. (p.124)

Ayar and Yalvac believe that the use of authentic learning environments, similar to those of the SRPP, is expected to lead to improved student understanding of the nature of science.

Chinn and Malhotra (2002) have studied the level of inquiry in many situations where IBL is being claimed and contend that the large majority of the activities fall in the simple confirmation or guided levels. They argue that the epistemology and reasoning processes evoked by simple inquiry tasks are qualitatively different from those evoked by authentic scientific inquiry. They develop a "taxonomy of differences between cognitive processes employed in authentic science and the cognitive processes needed for simple inquiry tasks. (p.176)"

Their taxonomy of the differences between the cognitive processes employed in simple inquiry tasks compared to those employed in authentic science identifies thirteen scientific cognitive processes, including aspects of generating research questions, designing studies, explaining results, developing theories, and studying research reports. They describe the differences between the cognitive processes of scientists and learners in simple inquiry activities in each of these areas. They then go on to analyze the epistemological differences between scientists and learners in simple inquiry activities for a range of dimensions, including the purpose of research, the nature of theory and reasoning, and the social construction of knowledge. Having pointed out the differences in cognitive processes and epistemology, they go on to argue for increased emphasis on higher-level inquiry tasks that more authentically model the epistemology and processes of scientists. The authors claim that much school activity that currently is claimed to be inquiry learning does not lead to the development of authentic scientific cognitive processes.

Based on the work of Chinn and Mahotra, a number of researchers have studied how to accomplish their recommendations. Researchers have looked at particular inquiry tasks and how to transform them from simple to authentic inquiry (Gröschner, Lockhart & Le Doux, 2005). These researchers point out the importance of constructing a careful scaffolding of activities to lead learners from confirmation inquiry to open inquiry. Marshall and Horton (2011) spent time analyzing the patterns in science classrooms to determine the relationship between content mastery, level of inquiry process, and level of cognitive processes. They concluded that:

> When teachers give students an opportunity to Explore the concepts prior to an Explanation, no matter whether the teacher or the students provide the Explanation, the students think more deeply about the content. If reasoning and critical thinking are instructional goals, then these results suggest that teachers should consciously provide opportunities for students to develop the ideas for themselves. In our observations, this did not equate to free discovery time, but rather to guided Exploration time in which students were given parameters by which to explore the concepts.
>
> When the goal is not deeper understanding but rather a focus on lower cognitive level skills, such as automating a certain procedure, then Exploring first may not be helpful. However, whenever the goal is to push toward deeper understanding, then teachers may be well advised to allow students ample opportunities to develop a plan, observe and collect data, and try to determine the underlying constructs. (p.100)

It is useful to note that theirs is not a one-size-fits-all solution, but recommends an adaptation of the pedagogical method to the desired level of cognitive skills. They conclude that when higher-order thinking skills are the goal, then the higher levels of inquiry are appropriate methods to achieve the goal. But when the goal is lower on the Bloom pyramid, direct instruction is more effective.

Other researchers have focused on the creative nature of inquiry. Note how Metz (2006) here concurs with Harwood's Inquiry Wheel model of the scientific process. Metz contends that he very nature of inquiry is a creative process. Students may follow a seemingly logical sequence when identifying a problem and designing methodology, but the actual research almost always requires flexible and innovative strategies. Practicing scientists often work in idiosyncratic ways and the creative processes of students should parallel these behaviors.

Another aspect of IBL research that needs to be considered is the concept of expertise. Glaser and Chi (1988), in their book on expertise, noted a number of characteristics of expert behavior:

- Experts excel largely in their own domain because they have a rich base of domain knowledge.
- Experts perceive meaningful patterns in their domain of expertise reflecting a well-organized knowledge base.
- Experts are fast and accurate at solving problems within their domain because with practice, many skills have become automated, freeing up cognitive resources for processing other aspects of the task.
- Experts represent problems at a deeper level than novices do because of their superior conceptual understanding.
- Experts spend a great deal of time analyzing and representing a problem before they start solving it. This provides the experts with a cognitive representation that allow them to infer the relevant relations and constraints.
- Experts have strong self-monitoring skills.

Hmelo-Silver and Nagarajan (2002) used this characterization of expertise as a framework to study the response of medical students to an authentic clinical drug-testing design scenario, compared to the response of expert, practicing physicians. They focused on the differences between the novices and the experts in their knowledge utilization, problem representation, scientific reasoning strategies, and metacognition. They found important differences between the novices and the experts in each of these aspects. They conclude that "providing cognitive guidance in the form of scaffolding helped support student learning as it supported them in reaching endpoints similar to those of the experts. (p.242)"

It would now be helpful to look at the work of researchers who have investigated the effects of authentic science learning on student outcomes. Frank LaBanca (2008), focusing on authentic inquiry, studied the issue of "problem-finding" in choosing a topic of research for science fairs. He found that "students conducted extensive background research to build their specialized scientific knowledge base" (LaBanca, 2008, p 82). While students used a variety of approaches in defining their research questions, the "problem finding process was idiosyncratic and required an extensive amount of time. Students worked through this process independently, but brokered and managed relations with others to advance their understanding and knowledge, and ultimately their projects" (LaBanca, 2008, p. 193).

Scallon (2006) conducted a study with eighth graders in the United States comparing the effects of scaffolded guided inquiry with authentic scientific investigation. She found that guided inquiry resulted in more gains in student conceptual understanding of specific content, but that authentic scientific investigation resulted in more gains in student understanding of the process of science and in students' abilities in practical reasoning. This finding confirms much of the research in this review as advocating for a scaffolded progression of levels of inquiry leading to authentic scientific learning. The author contends that the SRPP accomplishes this very well.

Finally, there is a body of literature studying the effects of successfully implemented IBL programs that provide scaffolding to enable learners to progress to authentic, open-inquiry research, while recognizing the need for concurrent content mastery. Michal Zion and his team have described the IBL program, Biomind, established in Biology courses in Israeli high schools (Zion et al, 2004; Zion, M., Cohen & Amir, 2007). Biomind is described as a program that enables students to conduct independent research under teacher guidance. The curriculum emphasizes the learning process, not just the outcome, and so students must reflect upon the work in progress. Moreover, the Biomind curriculum follows the principles of authentic inquiry. Biomind may improve students' scientific thinking abilities, expand the guidance aspect of teachers' work, and inspire curriculum developers to further emphasize inquiry (Zion et al, 2004). They do note the importance of teachers employing teaching practices that cover a wide range of methods, from confirmation inquiry through guided inquiry to open inquiry in order to ensure student competence and success in conducting their independent research.

Edelson (1998) surveyed a series of initiatives that used technology to aid in the development and implementation of authentic science learning programs. Some of these include the CoVis Project, the Global Lab Project, Kids as Global Scientists, and ScienceWare. Edelson studied how the technology used in these initiatives adapts tools used by scientists to make them suitable for the knowledge and ability level of the students so that they have the opportunity to engage in authentic scientific practice. The technology also provides platforms for communication and collaboration to enable students to “engage in dialogue with a community of science practice” (p.11). These projects help teachers design learning environments which make “uncertainty, commitment, and social interaction over science a central part of student’s activities” (p.12).

Inquiry Only

While there is broad consensus on the benefits of IBL and the necessity of ensuring learner engagement in open-inquiry to maximize these benefits, there has been a tendency, as there often is in education, for the pendulum to swing too far.

There have been criticisms of IBL by scholars who have observed the tendency by some educators to advocate pure open-inquiry, or "discovery-learning", with little understanding of the equal importance of content mastery in authentic inquiry (Chiappetta & Adams, 2004). Richard Mayer (2004) argues against pure discovery-learning: "I do not object to the idea that constructivist learning is a worthwhile goal, but rather I object to the idea that constructivist teaching should be restricted to pure discovery methods" (p.14). He compares student outcomes of pure discovery methods to those in guided inquiry methods. Mayer shows that in pure discovery methods, while there may be significant behavioral activity, the cognitive activity is limited in both depth and value. He shows that "Students need enough freedom to become cognitively active in the process of sense making, and students need enough guidance so that their cognitive activity results in the construction of useful knowledge" (p.16), and only guided inquiry provides this. Edelson (1998) supports this position when he states that:

> Effective science education will always consist of an appropriate balance between didactic instruction and hands-on activity. Meaningful science practice at any level requires an understanding of relevant fundamental science principles. It is a mistake to believe that the right activities will allow students to discover those principles entirely on their own, just as it is wrong to believe that they will understand them as a result of memorizing them. Students should have the opportunity to acquire and apply knowledge through scientific inquiry, as well as to expand and structure their knowledge through lectures and readings (p.17).

Note again how well the SRPP adheres to the principles being advocated by Edelson. While Mayer and Edelson use different terminology, the meaning is the same. The SRPP's emphasis on 'mastering current knowledge (Edelson's 'didactic instruction') leading to 'creating new knowledge' (Mayer's 'construction of useful knowledge') is clearly supported by the literature as an effective method of science education.

Kirschner et al (2006) also argue against pure inquiry and for guided inquiry. They maintain that our knowledge of human cognitive architecture, expert–novice differences, and cognitive load, indicate that minimally guided inquiry is less efficient and less effective for novice learners.

> Any instructional procedure that ignores the structures that constitute human cognitive architecture is not likely to be effective. Minimally guided instruction appears to proceed with no reference to the characteristics of working memory, long-term memory, or the intricate relations between them. The result is a series of recommendations that most educators find almost impossible to implement—and many experienced educators are reluctant to implement—because they require learners to engage in cognitive activities that are highly unlikely to result in effective learning. As a consequence, the most effective teachers may either ignore the recommendations or, at best, pay lip service to them (p.76).

They argue that the "sage-on-the-stage" is still necessary and effective for novice learners, and that the currently popular "guide-on-the-side" leads to frustration and lack of progress for novice learners. While constructivism as a learning theory is valid, many in science education have adopted a rigid interpretation of its implications for the classroom which is inappropriate for novice learners. "The major fallacy of this rationale is that it makes no distinction between the behaviors and methods of a researcher who is an expert practicing a profession and those students who are new to the discipline and who are, thus, essentially novices" (Kirschner et al, 2006, p.79). They show that "Direct instruction involving considerable guidance, including examples, resulted in vastly more learning than discovery." (Kirschner et al, 2006, p.79).

It must be noted that there are scholars who have responded to these criticisms of IBL with the contention that Mayer and Kirschner et al have misrepresented IBL. Schmidt, Loyens, van Gog and Paas (2007) have argued that, while they agree with Mayer and Kirschner et al's contention that guided inquiry is more effective than pure discovery, they maintain that IBL, correctly implemented, does not advocate pure discovery for novices, but rather a scaffolded process of leading novice students from confirmation inquiry, involving high levels of guided instruction, gradually through to open inquiry, with levels of direct instruction being adapted to the needs of the students as they progress from novice towards expert status.

From its description in Chapter 1, it is clear that the SRPP accounts for the "distinction between the behaviors and methods of a researcher who is an expert practicing a profession and those students who are new to the discipline" (Kirschner et al, 2006, p.79). The SRPP, in accordance with research, focuses first on helping novices master the content and processes of science, gradually leading them to the point where they can conduct original entry-level research, modeling the behaviors of experts.

Inquiry in University Science

A significant body of literature has investigated the effects of Inquiry-based learning at the University level. One of the important areas in the study of IBL focuses on the incorporation of authentic research learning into the classroom experience, while another area focuses on creating opportunities for students to collaborate with faculty in authentic science research. We will begin by looking at the first area, which mirrors the SRPP's implementation of authentic research into courses at the secondary school level.

Authentic inquiry at the undergraduate level. Scholars have studied the benefits and challenges of integrating authentic research into the undergraduate science curriculum. This has obvious parallels with the well-established authentic inquiry movement in lower education, as well as with the SRPP being studied in this research.

In an article in the Times Higher Education Supplement, Alan Jenkins (2007), of the Reinvention Center for Undergraduate Research in the UK, argues that undergraduate participation in scholarly inquiry is a key part of preparing them for participation in the knowledge economy of the 21st century. He quotes Bill Rammell, then UK Minister for Higher Education as saying in October, 2006: "We want all students to access the benefits exposure to teaching informed by research can bring... We believe an understanding of the research process - asking the right questions in the right way, conducting experiments and collating and evaluating information - must be a key part of any undergraduate curriculum" (p.1).

In a paper published in 2001, Jenkins (2001) considers the issues involved in integrating research into classroom teaching. He begins with a review of the literature on research and teaching, which leads him to conclude that the "common belief that teaching and research are inextricably intertwined is an enduring myth" (p.11). He then argues for a rethinking of the link between teaching and research in a way that is essentially the same as the calls for authentic inquiry in lower education by scholars such as Edelson (1998) and Roth (1995). He states that "students' understanding of the research process and ability to do research may be a vital 'key skill' and thus should be central to the curriculum for all/most students" (p.20), and thus he contends that "All higher education institutions and all degree programs should educate all students to understand how knowledge is constructed through research and to understand the research process. Knowledge should be presented as tentative, uncertain and of utter fascination" (p.19). He goes on to argue that achieving this requires that we "educate all students through processes of active 'constructivist' learning, which attempt to parallel the research processes in the disciplines students (and staff) are studying" (p.19). The parallels with authentic inquiry in lower education, and with the SRPP, are, again, obvious.

We will now review the literature on two programs that are attempts to integrate authentic inquiry into the undergraduate science curriculum. The first, CASPiE, the Center for Authentic Science Practice in Education, is a US-based effort described by Wink and Weaver (2009). CASPiE, initiated in 2004, is an attempt to integrate authentic inquiry experiences into an undergraduate biology curriculum. The course consists of a series of modules that are written by researchers based on their current work. The students are led through a series of knowledge and skill acquisition activities in the first part of the module, and then given problems that involve a part of the researchers' current work. The students then conduct research, as part of the course, which hopefully results in findings that are useful as a part of the researchers' continuing project.

Russell (2010) conducted a study comparing student outcomes in three different undergraduate biology courses: the first with a traditional (verification style) lab program, the second with an open inquiry-based (but non-authentic) lab program, and the third with a research-based (CASPiE) lab program. She studied the effects of these three programs on student attitudes about the lab and about science, on student content mastery, and on student understanding of the nature of science. Russell found that the comparison between traditional and inquiry results was mixed, with inquiry producing increased gains in some areas, no difference in others, and even decreased gains in a few areas. But the participants in the CASPiE program showed clearly higher gains in all areas that were studied. This underscores the importance of authenticity in the inquiry to which a learner is exposed, and increases levels of confidence in the efficacy of the SRPP.

A second program that we will review is the TELRI, Technology Enhanced Learning in Research-led Institutions, a UK effort out of the University of Warwick. Roach et al (2001) describe TELRI as an attempt to integrate research-based learning into the undergraduate science classroom through the use of technology and the tools it can offer to educators. It was founded on a belief that learners in the 21st century needed to experience Adaptive Learning rather than the more traditional outcomes of education, Adoptive Learning, as described in Table 2.2. Roach et al advocate redesigning courses with a view to promoting Adaptive Learning outcomes, using technology to enhance the traditional classroom-based methods. They encourage developing higher order thinking skills through student interaction with original material in the course and creation of original student investigations, with reporting on the findings and peer-review an essential component made possible with technology.

Table 2.2: Adoptive versus Adaptive Learning (Roach et al, 2001)

Adoptive Learning	**Adaptive Learning**
Knowledge and Practice of...	***Formation and Generation of…***
Facts, Assertions, Rules and Laws Terminology, Language and Protocols Techniques and Procedures Organization and Structure Established Principles and Relationships	Personal Interpretation and Meaning Arguments, Reasoning and Justification Evaluation and Decisions Synthesis and Conceptualization Originality, Creativity and Innovation

TELRI provides a template for redesigning courses based on these principles along with a platform of technology-based tools that enable and enhance the learning in the redesigned courses. Dempster (2003) evaluates the implementation of a TELRI course in terms of student outcomes. She notes that the TELRI approach is "not just subject matter, but the development of the kind of investigative techniques that encourage high-order thinking. In other words, we encourage learning that is based on knowledge construction – the 'imaginative extension of scholarship' – rather than merely its acquisition" (p. 132). Dempster points to outcomes of the TELRI project as including increased quality of student work, gains in the range of higher order thinking skills, and increased student confidence in discussions and collaboration.

Learning science through research. A second important effort focused on increasing the authenticity of students' experiences in undergraduate science is to incorporate student participation in scientific research into the undergraduate experience. This involves organizing participation by students, as interns, in ongoing research being conducted by practicing scientists.

The literature in this area uses the phrase "authentic research", which has been described by McKinney and Sadler (2010) as "opportunities for learners to work on scientific research with practicing scientists. These experiences tend to be situated in working laboratories and field sites. Students engaged in authentic research work as a part of a larger team of investigators that can include graduate students, postdoctoral fellows, lab technicians, and faculty members" (p.43). They conducted a review of the literature and found clear evidence that student participation in authentic research results in increased self-efficacy, confidence, skill mastery, the processes of science, and communication skills. Their survey showed that there was a relation between student gains and the nature of the participation in the authentic research, with students who participated only as low-level lab workers showing the lowest gains. They conclude that:

> Involving students in ongoing research projects such that they follow established routines may provide a practical way of engaging the students. However, if these experiences do not evolve to include more epistemically (sic) demanding practices such as data analysis, question posing, and hypothesizing, then learning gains on higher-order outcomes will likely be limited (p.51).

It is clear from this review that the nature of the student participation in the research is as important as the participation itself. It should be noted that the SRPP involves students in all aspects of authentic research, so would be expected to offer significant gains as well.

Seymour et al (2004) conducted a three-year study of the effects of undergraduate participation in summer research experiences. They studied student perceptions of the experience and found overwhelmingly positive responses. The greatest perceived gains due to participation in research experiences included gains in "thinking and working like a scientist" and "increased confidence" in scientific skills. Seymour et al contend that the gains in "thinking and working like a scientist" refer to gains in higher order inquiry skills such as their ability to bring their knowledge, critical thinking skills, and problem solving skills to bear on research related problems. Other benefits of the experience that were reported by students included increased communication skills, although most students reported increases in oral presentation skills, with only a small fraction (7%) reporting increased writing skills. It is worth noting that while this model of student participation in scientific research yielded little benefit in writing, it is expected that the SRPP, with its focus on students writing reports on their authentic IRP's, and then papers publishing their findings, will yield significant benefits in writing skills.

Lopatto (2007) continued the work of Seymour et al, with efforts to quantify the benefits of undergraduate participation in scientific research. He developed a Survey of Undergraduate Research Experience to study student perceptions. The results of his research support Seymour et al's findings, with student gains reported in the research process, scientific problems, and lab techniques, as well as personal gains reported in satisfaction, tolerance for obstacles, and working independently

Hunter et al (2007) looked at undergraduate research in which the undergraduates worked collaboratively with university faculty as "apprentices of authentic science research work". They define "effective undergraduate research" as "an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline" (NSF, 2003, p. 9). It is noteworthy that the SRPP can be similarly defined, so can be expected to have similar outcomes.

Hunter et al found that as a result of these experiences students "began to exhibit behaviors and attitudes that underpin research work, such as curiosity and initiative, becoming less fearful of "being wrong," and more willing to take risks. 'I now feel confident that I can walk into any room with any instrument and figure out how to make that instrument work' " (p.54). It is worth quoting at length from their study:

> Overwhelmingly, students define Undergraduate Research as a powerful affective, behavioral, and personal discovery experience whose dimensions have profound significance for their emergent adult identity, sense of career direction, and intellectual and professional development. Students' observations on gains related to their confidence to do science and to contribute meaningfully to research reflect the affirming nature of the working relationship they experience with their faculty research advisors and highlights the significance of the multiple roles faculty members play as research advisors…. Almost two thirds of the gains statements reported by faculty and students describe growth in understanding both salient areas of science and how to apply knowledge to the professional practice of science; concomitant development of

> students' confidence and competence in doing research; personal growth in the attitudes, behaviors, and temperament required in a researcher; and the beginnings of identification with and bonding to science as an enterprise. (p.69)

It is interesting to contrast these results with the findings of Seymour, who studied all types of undergraduate research experiences, and found gains of much less importance.

Gutterman (2007) surveyed the Seymour and Hunter studies, along with others to look at the effects of undergraduate research experience on learners. Gutterman found that the strength of the mentor relationship was crucial to learner gains, but questioned whether the time and energy commitment of the faculty was worth the resulting benefits, whether that time and energy might be directed elsewhere with better results.

Osborne and Karukstis (2009) with the Council on Undergraduate Research in the United States looked at the effects of undergraduate involvement in "collaborative research, scholarship, and creative activity". They define this as "an inquiry or investigation conducted by an undergraduate in collaboration with a faculty mentor that makes an original intellectual or creative contribution to the discipline" (p.41). They contend that all forms of undergraduate research, scholarship, and creative activity can be characterized by four features: mentorship, originality, acceptability, and dissemination. Mentorship involves a collaborative interaction between a faculty mentor and a student in a scholarly project in which the student is intellectually engaged, with the faculty mentor providing guidance toward deeper intellectual engagement on the part of the student. Originality refers to the fact that the project must result in novel findings that add to the body of knowledge in the field. Acceptability suggests that the work must employ methods and techniques that are appropriate and recognized in the field. Finally, dissemination means that the project must include a final product that is peer-reviewed and published in a manner that is consistent with disciplinary standards. It is clear that these four features are a part of the process which students in the SRPP experience at ISB.

Osborne and Karukstis (2009) outline the benefits of undergraduate research to the institutions, to the faculty, and to the students. Given the focus of this research, we will here only look at their discussion of the benefits to the students. They identify the benefits to the students related to cognitive and intellectual growth, and personal and professional growth. Students who participate in collaborative research have been shown to make personal gains in mastering content and contextual knowledge, creativity and critical thinking skills, confidence and independence, commitment to the philosophy of life-long learning, communication skills, and technical skills within the discipline. They have been shown to make academic and professional gains in terms of increased grades, graduation rates, participation in academic life, collaborative relationships, integration into the culture of the discipline, and increased rates of acceptance to graduate education programs. Osborne and Karukstis contend that participation in undergraduate research has consistently been shown to be a transformative experience in the lives of the students.

While the majority of programs have focused on offering undergraduates the opportunity to participate in scientific research work, only a few programs have offered high school students that opportunity. Given the rarity of this type of program, there is little literature on the topic. One study, by Roberts and Wassersug (2008), did a survey of summer research programs in the USA that offered secondary students the opportunity to work in a research laboratory. They looked at the relationship between participation in these programs and students staying in science. Their findings were, unsurprisingly, that there was a strong correlation between student participation in the program and likelihood of entering and maintaining a science-related career. There was no evidence that participation in the programs *caused* students to stay in science. It is quite likely that students with a previously formed affinity for the sciences self-selected for the program, resulting in the correlation discovered.

Another program that has been studied, by Terry Le (2010), is the STAR Program, a program of the University of Southern California offering high school students in a nearby school the opportunity to work in a collaborative, mentored relationship at a research lab at the university for at least 10 hours a week for one year. Le studied the impact of the program on students' interest in science and attitudes toward science classes. Le's results show that participation in the STAR program had a significant positive correlation with student interest in pursuing science in university, in their attitudes toward science, on their understanding of the principles of science, and on their knowledge of scientific techniques and procedures. Again, there is no evidence that participation in the STAR was the cause of these outcomes. It is likely that students who were predisposed to these outcomes, for other reasons, gravitated to the STAR program, resulting in the correlation.

Winkleby et al (2009) studied the effect of the Stanford Medical Science Youth Program, a five-week summer research opportunity for high school students. They conducted a 21-year longitudinal study of the participants of the program. Their results, similarly to Le's, show that students who participated in the program were more likely than their peers to enter university, to choose to study science in university, to complete a four-year degree and to choose a science-related career.

Scientific Journals for Students

Undergraduate Journals. The calls for science education to integrate authentic research into the curriculum (Hensel, 2012) have led some university faculty to advocate the establishment of scientific peer-reviewed journals whose goal is to provide a place for undergraduates to publish their research findings. Given that much student work, while original, is not considered important enough in the field to warrant space in the leading journals, it is suggested that these second-tier journals be established. It has been advocated that these journals can play a role in an important aspect of science that is often overlooked in science courses: the process of scientific writing, peer-review, and publishing (Guilford, 2001). Ariel Reno (2009) conducted a survey of undergraduate journals in the United States and found 42 journals in North America covering all subjects. The author has also found a significant number of undergraduate journals sponsored by universities around the world. This shows that there is significant support for undergraduate scholarly journals.

Burns and Ware (2008) looked at the benefits and opportunities of undergraduates publishing their work from the perspective of both the students and their faculty. They found a range of benefits associated with the publication of a paper, above and beyond the well-established benefits of conducting authentic research. The benefits of publishing include the mentoring relationship with a faculty member during the publication process, improved communication and writing skills, sense of accomplishment and confidence in the academic world, and improved chances of acceptance to graduate education (Ho, 2011). It is expected that the SRPP, with its similar mentoring relationship during the publication process, will demonstrate similar results for students who publish papers in the *Journal of Science*.

While undergraduate journals have many advocates, not all are convinced. Gilbert (2004) argues that the benefits to students who publish are not worth the cost to faculty in the time, effort, and stress of helping their students prepare their work for publishing. But Gilbert is definitely in the minority in his opposition to undergraduate journals.

Two case studies have been conducted examining the challenges involved in running a journal and the benefits to its student-based editorial staff. Both studies found significant benefits to its staff, but the challenges of time commitments, management issues, and long-term sustainability in the face of high student staff turnover were significant issues (Farney & Byerley, 2010; Ho, 2011). Jungck (2004) advocates strongly for undergraduate opportunities to publish. He argues that only with the opportunity to publish will students fully engage in the research process, which has proven such a transformative experience for learners. It is recognized that journals aimed at publishing student work must be run slightly differently from standard academic journals. Part of the mission of student journals must be working with the author to a much greater extent than a standard journal does. Student journals must focus on helping students in all aspects of preparing their research paper for publication, from analysis and conclusions, to writing and layout (Chancey, 2003).

It is interesting to note the similarities in the conclusions of the literature on undergraduate journals and what the author has found in his experience as Editor of the *ISB Journal of Science* for the past seven years. This leads the author to believe that the results of this study on the effect on high school students of conducting and publishing research will mirror the experience of the undergraduate journals.

Journals for secondary school students. While an extensive search was done for literature on secondary-school-based scientific journals, no research was found. This is not surprising, given that the author could only discover the existence of a small number of peer-reviewed scientific journals that publish the work of high school students. A representative selection will be reviewed here.

One of the oldest of these, older even than the *ISB Journal of Science*, is *Teknos:* a Journal of Science, Mathematics and Technology published by students at the Thomas Jefferson High School of Science and Technology (TJHSST) magnet school in Alexandria, Virginia, USA. This is a print-only journal. According to an article on Wikipedia, the journal publishes “papers produced by original scientific research and articles… written mostly by students from” TJHSST (Teknos, 2014). It is unclear what the quality and level of the articles or the peer-review process, as no samples of the journal or information on the publication process could be obtained.

A more recent start-up is the *Broad Street Scientific* (*BSS*), “the North Carolina School of Science and Mathematics’ (NCSSM) Journal of Student STEM Research”, first published in 2011. The NCSSM is a selective secondary school in the USA focusing on sciences and mathematics, with nearly a third of students participating in mentored research with university or industry mentors (Broad Street Scientific, 2014). The *BSS Journal* “showcases some of the most interesting and complex math- and science-centered research projects explored by students at NCSSM”. These are selected by the editorial staff made up of students, with a faculty advisor. (Broad Street Scientific, 2014). There seems to be no formal peer-review system for the papers, although this cannot be ascertained from the information on the journal website. Most of the papers were the results of projects done in collaboration with university or industry mentors at their research facilities.

Journys: Journals of Youths in Science is a journal publishing a mixture of articles and peer-reviewed papers (Journys, 2014). Papers are contributed from a group of high schools in California, USA, with its first issue in 2012. Like Broad Street Scientific, it has a student-based editorial staff with a faculty advisor. The peer-review system, while poorly described on the website, seems to use university professors as reviewers (Journys, 2014).

Another journal, the *Journal of Emerging Investigators* (*JEI*) is a peer-reviewed journal published by the Harvard Graduate School of Arts and Sciences. (JEI, 2014) It publishes original research from Middle and High School students. Most of the papers are the results of special projects done by students outside their normal science courses. The *JEI* was founded in 2011 and publishes online on a rolling basis. The peer-review process is similar to the process used by the *ISB Journal of Science*, with a component of guidance designed to "both improve the manuscript and to help teach the students about their project" (JEI, 2014).

Finally, the *National High School Journal of Science*, started in 2009, also publishes mostly articles, with some original research papers (NHSJS, 2014). The research papers are subject to peer-review by scientists. Most of the papers are, again, the results of students' work with mentors in universities or industry. The editorial staff is made up of high school and university students.

These journals publish papers that are based on extra-curricular research projects by students who are academically gifted and strongly motivated. These select few are given access to university or industry facilities and mentors. None of these journals are integrated into a course-based research program in secondary science, as is the SRPP's *Journal of Science*.

Student Research and Publishing Program in Secondary Science

The previous sections have reviewed the literature on Inquiry-Based Learning programs in science, Authentic Science programs, programs allowing undergraduate and secondary students to participate in scientific research, and scientific journals publishing the work of undergraduate and secondary students.

Looking at the SRPP in light of the literature just reviewed, it is obvious that the SRPP is unique. The SRPP is a philosophically coherent program, focusing students on becoming experts in the scientific process, from mastering current knowledge, to creating new knowledge through scientific investigation, to possibly publishing their work in an entry-level, peer-reviewed, scientific journal. The SRPP, being a program that is integrated into the science courses of a school, allows all students the opportunity to experience and master the scientific process, not just the academically gifted and strongly motivated. The SRPP, with its *Journal of Science* publishing entry-level work done independently by secondary students, allows all students to experience authentic scientific research, and offers all students the possibility of publishing their work, not just students at schools that can offer access to university facilities and mentors. Finally, the SRPP, with its research done within the context of the normal science program, conducted in a typical secondary science lab with typical equipment, offers most other secondary schools around the world the possibility of implementing the program.

Looking further back over this review of the literature on science education, we can see that the SPRR follows best-practice suggested by the literature. The SRPP uses a mix of direct instruction and inquiry, depending on the nature of the learning. In the IBL part of the program, students are carefully scaffolded from confirmation inquiry to open inquiry, acquiring the behaviors, skills and cognitive competencies required by novices to become expert at each level of inquiry. The SRPP, by publishing entry-level student research in the *Journal of Science*, is expected to increase student engagement by ensuring the scientific authenticity of students' open-inquiry investigations. The literature shows that authenticity in inquiry may increase learner gains in content mastery, higher-order thinking skills, understanding of the nature of science, and attitudes to science.

As far as the author can determine, the SRPP, with its *ISB Journal of Science* as a school-based, peer-reviewed scientific journal publishing the original work of high school scientists that is conducted as an integral part of the course, is the only program of its kind in the world.

Unfortunately, given that the SRPP seems to be unique in the world, no literature specifically studying an SRPP-type program has been found after extensive searches. As can be seen in the previous sections, there is much research on a wide range of all individual aspects of the SRPP: IBL, Authentic Science, Student Research, and Journals for students. But there seems to be no current research in the literature directly studying an SRPP-like program.

While this makes it impossible to place this research in context, it does dramatically underscore the significance of, and need for, this research, as there is currently no literature addressing a program such as the SRPP.

The Process of Science

The process of science, while a part of the larger philosophical consideration of the Nature of Science (NOS), must be considered distinct from it. The processes of science can be understood to be carried out on the foundation and within the context of the NOS. We will begin our review of the literature with a look at scholars' research on NOS. There is a large body of literature looking at the philosophy and nature of science with different authors and organizations discussing it from different perspectives and with different goals (Abd-El-Khalick, Bell & Lederman, 1998; Abd-El-Khalick, 2001; Aclufi, 2005; Carpi & Egger, 2011; Laitko, 2000; NSTA, 2000; VAMSC, 2010). As with all philosophers, there is much disagreement, with debate over the relative importance of the various aspects, and even over the meaning of a specific phrase, but in general, there is broad agreement on the main aspects of NOS (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). Liang et al (2006) conducted an extensive survey of the literature, including the most respected organizations and scholars in the field, and have distilled current thinking on NOS into seven aspects of most importance in the context of K-12 science education. They have summarized this description of NOS as follows:

1. **Tentativeness of Scientific Knowledge:** Scientific knowledge is both tentative and durable. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes.

2. **Observations and Inferences:** Science is based on both observations and inferences. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.

3. **Subjectivity and Objectivity in Science:** Science aims to be objective and precise, but subjectivity in science is unavoidable. The development of questions, investigations, and interpretations of data are to some extent influenced by the existing state of scientific knowledge and the researcher's personal factors and social background.

4. **Creativity and Rationality in Science:** Scientific knowledge is

created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world. Scientists use their imagination and creativity throughout their scientific investigations.

5. **Social and Cultural Embeddedness in Science:** Science is part of social and cultural traditions. People from all cultures contribute to science. As a human endeavor, science is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.
6. **Scientific Theories and Laws:** Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Theories are well-substantiated explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; theories explain laws.
7. **Scientific Methods:** There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is constructed and developed in a variety of ways including observation, analysis, speculation, library investigation and experimentation.

Liang et al have developed a questionnaire to measure students' understanding of NOS. That questionnaire will be used in this research.

While it is important to establish an understanding of relevant aspects of NOS, the nature of the processes of scientific investigation is also central to the SRPP. Carpi and Egger (2011) have described a number of characteristics of the process of science as follows:

1. Science is a process of investigation into the natural world and the knowledge generated through that process.

2. Scientists use multiple research methods to study the natural world.
3. Data collected through scientific research must be analyzed and interpreted to be used as evidence.
4. Scientific theories are testable explanations supported by multiple lines of evidence.
5. Scientific knowledge evolves with new evidence and perspectives.
6. Science benefits from the creativity, curiosity, diversity, and diligence of individuals.
7. Science is subject to human bias and error.
8. The community of science engages in debate and mitigates human errors.
9. Uncertainty is inherent in nature, but scientists work to minimize and quantify it in data collection and analysis.
10. Scientists value open and honest communication in reporting research.
11. Science both influences and is influenced by the societies and cultures in which it operates.
12. Science is valuable to individuals and to society.

Note that most of these characteristics, while focusing on the behaviors, assumptions, and attitudes of scientists in their work, have direct parallels in the description of NOS by Liang et al (2006).

Finally, we must review the literature describing the behaviors of scientists during investigation. As this was primarily the focus of the discussion of the Process of Science in Chapter 1, we have already discussed the literature on this aspect in depth. To summarize, the act of creating new knowledge in scientific investigations is often misrepresented in science education with its linear “scientific method” of textbook fame (Krajcik & Merritt, 2012). A much more creative, complex, and variable pattern of behaviors is the reality in scientific practice.

Harwood (2004) has modeled the scientific process as an Inquiry Wheel, as shown in figure 1.2 and discussed in detail in Chapter 1. The Inquiry Wheel better models the creativity, complexity and variability of real scientific activity.

The author, however, believes that the Inquiry Wheel, with its goal of describing the scientific process as practiced by experts, is flawed as a tool for use in secondary science education. Secondary science students are novices, and novices have very different needs and learning processes than experts. Harwood's Inquiry Wheel results in an under-emphasis of two of the parts of the scientific process that novices need to focus on: Mastering current knowledge, and, Publishing the newly created knowledge. It is suggested that the author's simplified three-part SRPP model of the scientific process, illustrated in figure 1.3 in Chapter 1, is a more useful way of representing the process of science for novice learners. The Inquiry Wheel can be used to elaborate on the complex nature of part 2 of the SRPP model, Creating new knowledge, as needed. The author believes that this SRPP model of the scientific process is more effective in communicating the process of science to secondary school science students.

21st Century Skills

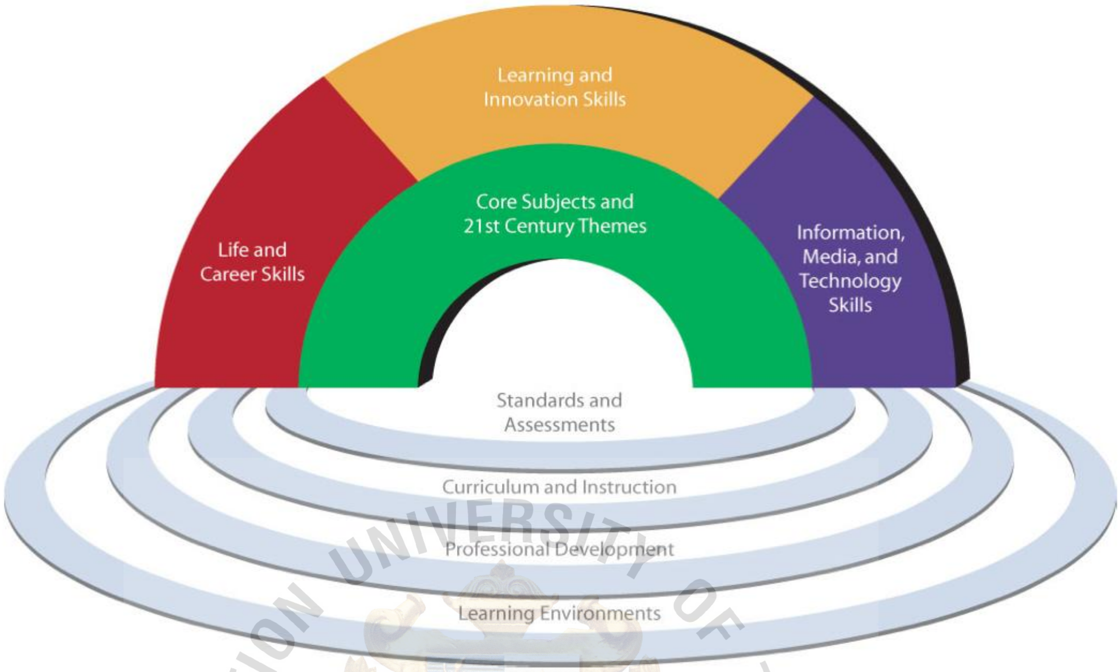
One last area of the literature that is important to review for this research is the field of 21st Century Skills. The demands on workers and members of society in the Information Age are very different than the demands during the Industrial Age. While it has been argued that most of the skills necessary for success in the new economy are not new, it must be acknowledged that these skills are needed by a much broader segment of society than during the Industrial Age (Silva, 2009). Given that the SRPP is expected to have an effect on student gains in precisely these skills, we need to spend some time looking at the literature that defines and describes them.

While many scholars and organizations have published work in this field, most lists of 21st Century Skills produced are almost indistinguishable (AASL, 2009; ASCD, 2007; NRC, 2012). Different authors use different names, but the main ideas are the same. Therefore, only the work of two of the most influential authors in the field will be summarized here.

Trilling and Fadel, of the Partnership for 21st Century Skills (P21) have published what has come to be a standard in the field, *21st Century Skills: Learning for Life in our Times* (2009). They begin by looking at current economic and social systems, and how they are different from in the past. Then they use this analysis to develop a series of characteristics which one needs to be successful in the modern world. Finally they create a framework describing the 21st Century Skills which students need, and discuss ways of reforming our educational system to ensure that our learners master them. They have developed a graphic to illustrate their framework, shown in Figure 2.2 on the following page.

The inner ring represents core subjects taught in schools and 21st century themes that must be mastered by learners in order to be successful. The outer ring, divided into three parts, represents the 21st century skills that must be mastered by all learners. The rings at the base represent school functions required to support learners. In the interests of brevity, only those skills that are relevant to the SRPP will be discussed here. The Learning and Innovation Skills consist of Creativity, both individual and collaborative; Innovation, both creation and implementation; Critical Thinking, inductive, deductive and systems thinking, as well as critical decision making and problem solving; Communication, in a variety of forms and contexts; and

Figure 2.2: 21st Century Student Outcomes and Support Systems (Trilling & Fadel, 2009)



finally, Collaboration, the ability to work effectively, productively, and respectfully with others towards a common goal.

The relevant Information, Media, and Technology Skills consist of Information Literacy, accessing, evaluating, using and managing information from a variety of sources; and ICT Literacy, using technology to create, organize, evaluate and communicate information. Finally, the relevant Life and Career Skills consist of flexibility, adaptability, initiative, independence, and responsibility.

It is expected that the SRPP, with its integration of authentic scientific research and publishing into secondary science, will increase learner outcomes in several of these important behavioral and thinking skills.

Summary

Having reviewed the literature on inquiry learning, authentic student research and publishing, the nature of science and process of science, and 21st century learning skills, in light of the SRPP, we have gained insight into what is known about the components of the program and the theory and practice underlying it, as well as into areas in which our understanding of the SRPP is limited. We have seen what is known regarding the benefits and challenges of programs that are similar to aspects of the SRPP. This allows us to analyze the program more fully and to design the methodology of the research with a more complete understanding of the possible benefits and limitations of the SRPP for the learner and the conditions and processes of its implementation.

CHAPTER III

RESEARCH METHODOLOGY

Overview of Research Objectives

The research objectives, presented again below for convenience, can be usefully divided into two parts. The first four objectives address the effects of the SRPP that is currently well established in IB Physics courses at ISB. These four objectives aim to determine the benefits and limitations of the SRPP, so that other educators can make an informed decision as to whether it is a program that they are interested in implementing in their school.

The fifth objective addresses a second aspect of the research: the development of a Model for Implementation of a Student Research and Publishing Program in another secondary school science program. This fifth objective will be approached differently from the first four objectives.

Given that the research objectives can be usefully divided into two parts with two different approaches, the methodology of this research will also be described in two parts, matching the two aspects of the objectives of the research.

The first part can be described as mixed methods investigations addressing the first four research objectives. The second part, also a mixed methods study, but with a different focus and emphasis, will address the fifth objective. The objectives of the research are re-stated here:

1. To determine the effect of the Student Research and Publishing Program on students' science-related attitudes.

2. To determine the effect of the Student Research and Publishing Program on students' understanding of the Nature of Science.

3. To determine the effect of the Student Research and Publishing Program on students' experimental research and publishing skills and attitudes.

4. To determine the effect of the Student Research and Publishing Program on students' 21st Century Skills.

5. To develop a Model for Implementation of a Student Research and Publishing Program in Secondary School Science.

Overview of SRPP and Research Design

This study aims to determine the effects of the SRPP on four areas of student outcomes, and then to develop a Model for Implementation of the SRPP in other schools. Before describing the details of the research design for each objective, an overview of the approach to the study is provided.

The study focuses on a comparison of two groups of students who completed the IB Physics courses at ISB. The first group, Group 1, was the Treatment Group. This group enrolled in the standard IB science program in grades 9 and 10, and then enrolled in the IB Physics course with an established SRPP integrated into the course in grades 11 and 12.

The second group, Group 2, was the Control Group, used for comparison. This group also enrolled in the standard IB science program in grades 9 and 10, but then enrolled in the IB Physics course with no SRPP in grades 11 and 12.

While the IB science program and the SRPP were described in detail in Chapter 1, it is helpful to review them here. The standard IB science program in grades 9 and 10, experienced by both the Treatment and the Control Groups, is an inquiry-based program that leads students from confirmation inquiry to open inquiry, with independent research projects required. The standard IB science program in grades 9 and 10 covers topics in Biology, Chemistry and Physics typical of North

American secondary school science curricula at that level. The science courses in grades 9 and 10, as is typical of North American curriculums, are approximately 120 hours of class time per year.

The IB Physics course, experienced by both the Treatment and Control Groups, is the standard course mandated by the International Baccalaureate Organization (IBO) covering prescribed theoretical content and laboratory components, with internally assessed laboratory criteria and skills and an externally assessed exam on the course content. The Higher Level IB courses are prescribed as 240 hours of class time spread over two years. This time is to be divided between covering the course content (180 hours) and conducting practical laboratory investigations (60 hours).

The SRPP, the focus of this research, is the experimental treatment, the difference between the Treatment and the Control Groups. The SRPP focuses students on a simplified three-part model of the scientific process. The program requires students to conduct authentic, original scientific research, with the possibility of publishing their findings in an entry-level scientific journal. The SRPP established at ISB requires no extra class time, nor does it take time from teaching content. The IB requires that 60 hours of the IB Science courses be devoted to the practical laboratory program. The SRPP merely changes the structure and focus of these 60 hours. The practical laboratory program is changed from a traditional approach to an approach in which the students are prepared for, and then conduct authentic, original research projects with an understanding of the possibility of publishing their work in an entry-level journal. Students whose work is selected for publishing take time outside of class to write the paper. The SRPP is described in more detail in the Background of the Study section in Chapter 1.

Summary of Conditions and Experiences of SRPP Students

In this study, the course conditions and experiences of students who participate in the SRPP in IB Physics will be compared to students who experience the standard IB Physics program at ISB. Table 3.1, on the following page, is presented to summarize the SRPP and to clarify the difference in conditions and experiences of students in the SRPP, compared to students not in the SRPP course.

From Table 3.1 one can see that students participating in the SRPP-based IB Physics course experience the same inquiry-based program in grade 9 and 10 as the Control Group. In grades 11 and 12, both the Treatment Group and the Control Group experience all aspects of a standard IB Physics course, with its IB-prescribed theoretical content and practical laboratory program. The only difference between the Treatment and Control Groups is that, first, the SRPP introduces students to the simplified model of the Process of Science (Figure 1.3) and uses that as the organizing principle of the course, and second, students are encouraged and guided to conduct authentic, original research and given the opportunity to have their work selected for publishing in the *Journal of Science*.

Expected Learning Outcomes. In the interests of gaining as complete an understanding as possible of the effects of the SRPP on student learning, the study looks at four different areas of learning that are important to science education: Science-related attitudes, Understanding of the Nature of Science, Research and Publishing Skills and Attitudes, and Development of 21st Century Skills. While it is unclear, following the evidence of the literature review, if the SRPP will cause significant improvements in all four areas, the author felt it was important to define both the benefits *and* the limitations of what the SRPP can do for students.

Table 3.1: Summary of conditions and experiences of the Control and Treatment Groups in the study.

Conditions and Experiences of the Students in the Control and Treatment Groups of the Study	**Group**	
	Control	**Treatment**
Standard ISB Grade 9 & 10 Science Program:	□	□
• Content in Physics, Chemistry and Biology typical of North American curricula (120 hrs/yr)	□	□
• Inquiry-Based Practical Laboratory program leading students from Confirmation Inquiry to Open Inquiry	□	□
• Required Independent Research Projects	□	□
• Emphasis on student writing and reporting skills with online ISB Science Writing Guide as supporting resource	□	□
Standard IB Physics Course:	□	□
• Duration: Two Years, Grades 11 and 12 (240 hrs total)	□	□
• Course curriculum content prescribed by the IB (180 hrs)	□	□
• Practical Laboratory program with required criteria and demonstrated skills prescribed by IB (60 hours)	□	□
• External Assessment of Content by IB	□	□
• Internal Assessment of Practical Laboratory IB-required criteria and skills by teacher	□	□
Student Research and Publishing Program:		□
• Duration: Two Years (Gr. 11 & 12) – Integrated into IB Physics Course as part of required 60 hr IB Lab Program		□
• Initial Introduction and continued, regular emphasis of simplified 3-part SRPP model of the Process of Science (Figure 1.3) as focusing structure of course		□
• Initial Introduction and continued, regular emphasis of the entry-level *Journal of Science* and the possibility of publishing research findings as a paper in the *Journal*		□
• Required authentic, original, scientific research investigations (3-4 projects during the 2-year course)		□
• Support provided in selecting and refining authentic, original research topics		□
• Emphasis on authentic scientific writing and reporting skills with online ISB IB Science Writing Guide as supporting resource		□
• Opportunity to submit research for peer-review and selection process		□
• Mentoring during process of writing, revising and publishing a scientific paper in an entry-level journal for selected students (Time outside of class)		□

The Treatment Group is hypothesized to have more positive science-related attitudes than the Control Group. This is expected as it has been shown that Inquiry-based learning has positive effects on student interest and attitudes (Trumper, 2006; Wolf & Fraser, 2008). This expectation is qualified by the fact that students in the Control Group also experience an inquiry-based science program, albeit without the emphasis on conducting and publishing authentic, original work.

In terms of students' understanding of the Nature of Science, it is hypothesized that students in the SRPP will have a greater understanding of the Nature of Science, due to their designing, conducting and reporting on authentic, original scientific investigations. Again, based on the literature, it is possible that the SRPP may have little or no effect compared to the Control Group, as it has been shown that improving student understanding of NOS requires direct instruction on the topic of NOS (Abd-El-Khalick, 2001), and the SRPP does not do this.

SRPP students are expected to show significant gains in the area of research and publishing skills and attitudes, compared to the Control Group. This is the heart of the SRPP, with a main focus of the program being the design, conducting, and publishing of authentic, original research. And the literature has shown convincingly that students engaged in authentic scientific research show significant gains in related skills and attitudes (Wink & Weaver, 2009; Roach et al, 2001; Seymour et al, 2004; Burns & Ware, 2008; Weston, 2012b).

Finally, SRPP students are expected to show significant gains, compared to the Control Group, in development of aspects of 21st Century Skills (Trilling & Fadel, 2009) that are associated with the design, conduct and publishing of authentic, original research. These aspects are expected to include creativity, innovation, problem solving, critical thinking, and flexibility, initiative and independence. It is possible that there may be no significant difference between SRPP and control students in the areas of Information and ICT Literacy, as students are expected to develop these skills effectively in the standard IB Physics program experienced by the Control Group.

Having reviewed the overall approach to the study, summarized the Control and Treatment conditions, and discussed expected outcomes it is time to address the research methodology of each of the objectives in detail.

Research Methodology

Objective 1: To determine the effect of the Student Research and Publishing Program on students' science-related attitudes.

Research Design

A quantitative approach is used for the first objective of this study. The straight-forward nature of the aspect being measured, along with the nature of the instrument being used, indicate that a quantitative study will be adequate to determine the effect of the SRPP on students' science-related attitudes.

Population

There was a population of N = 166 students for Objective 1 of the research. This population consisted of two groups. (It should be noted that the population for Objective 1 was identical to the population studied in Objectives 2-4.) The first population group, the Treatment Group, included all ISB students who experienced the SRPP in their two-year IB Physics classes. This included students in IB Physics in the graduating classes of 2010, 2012 and 2014. This group had a population of 118 students.

The second group, the Control Group, consisted of ISB students who experienced the normal ISB science program in their two-year IB science program, but with no exposure to the SRPP and no opportunity to publish their work in the *ISB Journal of Science*. This included students in IB Physics in the classes of 2011 and 2013. This group had a population of 48 students.

To review, the conditions experienced by the Treatment Group and the Control Group are as follows. Both the Treatment and Control Groups experienced the same standard grade 9 and 10 ISB science program described in Chapter 1. The standard ISB science program is an inquiry-based program, with students in grades 9 and 10 experiencing a scaffolded series of labs starting from guided-inquiry through to the open-inquiry of the Independent Research Projects. After completing grades 9 and 10, both Groups enrolled in IB Physics, with the same IB course content, and IB course criteria. Students in the Control Group entered the standard IB Physics course, but without the SRPP. The standard IB Physics course requires students to demonstrate content mastery, as well as competency in research skills including designing, conducting, analyzing and reporting on experimental investigations.

The difference between the Treatment and Control Groups is that the Treatment Group experienced the SRPP integrated into the standard IB Physics course. This was described in detail in chapter 1, but to summarize, it means the Treatment Group was introduced to the simplified 3-part model of the process of science (Figure 1.3) at the beginning of the course, with a focus throughout the course on using the course content to 'create new knowledge' through original research, and the possibility of publishing in the *Journal of Science*.

Sample

The sample of the population for Objective 1 needed for a 95% Confidence Level in the findings was N = 116. The size for a 95% Confidence Level for the Treatment and Control Groups was N = 90 and N = 43, respectively (Krejcie & Morgan, 1970). The sample consisted of all students who consented to participate in the study. Consent was obtained by asking each student in the population to fill out a Consent Form, shown in Appendix A.

Research Instrument

The instrument used to address the first objective was the Test of Science-Related Attitudes (TOSRA), developed by B. Fisher (1981) and modified by C. Ledbetter and R. Nix (2002). The TOSRA has been used in various forms and languages in a variety of contexts in many different countries (Ali, 2013). The TOSRA measures seven aspects of student attitudes, namely:

Factor S Social Implications of Science,
Factor N Normality of Scientists,
Factor I Attitude to Scientific Inquiry,
Factor A Adoption of Scientific Attitudes,
Factor E Enjoyment of Science Lessons,
Factor L Leisure Interest in Science, and
Factor C Career Interest in Science.

The TOSRA instrument has been shown to be valid and has strong reliability, with a Cronbach's Alpha of 0.82 (Fraser, 1981). The version used in this research was developed by Ledbetter and Nix (2002) and consists of 35 items Likert-scale type items, with five items measuring each of the seven scales.

In the TOSRA, students are asked to respond to each item on a five-point scale ranging from 'strongly disagree' to 'strongly agree'. The response to each item was converted to a numerical five-point interval scale with 1 being 'strongly disagree', 3 being 'neutral', and 5 being 'strongly agree'.

A student's responses to the five items making up each of the seven factors was averaged, with the resulting factor score representing the level of the student's 'Science-Related Attitude' for that factor. This factor score was interpreted as follows:

4.51 – 5.00	Very Positive
3.51 – 4.50	Positive
2.51 – 3.50	Neutral
1.51 – 2.50	Negative
1.00 – 1.50	Very Negative

For example, if a student responded with an average factor score of 4.20 for Factor L: Leisure Interest in Science, the student was regarded as having a "Positive" Leisure Interest in Science.

The instrument was used with the permission of the original author as well as the author of the modified version of the instrument used in this research (Appendix B.1). The instrument is shown in Appendix C.1.

Collection of Data

Obtaining Assent of the Participating Sample

Before collecting data, student and parent consent was sought according to the guidelines established by *The Ethical Guidelines for Research on Human Subjects in Thailand 2007* (Sueblinvong, Mahaisavariya & Panichkul, 2007). Electronic and hard copy consent forms were developed and distributed to members of the populations of the two groups. Consent forms were also distributed to the parents of students who were under 18 years of age. Students and parents had the option of declining to participate in the research with no negative consequences. It was expected that a certain percentage of the population would decline to participate. Examples of the student and parent consent forms are shown in Appendix A. Permission to conduct the surveys and access student data was also obtained from the principal of ISB High School and the ISB Head of School. Consent obtained for Objective 1 was applicable to participation in all aspects of the research, covering all five objectives.

Contact Information for Graduates

The first type of data requested from ISB was the current emails/contact information of the members of the Treatment and Control Groups who are currently studying at university and are no longer enrolled at ISB. This allowed consent forms to be sent to them to obtain their consent for participation in the study. Following the return of consent forms from all members of the population described previously, data collection could begin.

Demographic and Educational Data

The first data collected was demographic and educational data. This data was collected for all students who consented to participate. Data collected included gender, cultural group, science and math courses taken in grade 12, science and math course grades, current or planned science major, and semesters of university completed when surveyed. Demographic and educational data collected for use in Objective 1 was used in Objectives 2 and 3 as well.

Because the members of the Control and Treatment Group were not randomly assigned, there was a high likelihood that the two groups were not equivalent with respect to several outside, uncontrolled variables that could have an impact on the dependent variables. It was thus necessary to test for differences between groups and correlations with dependent variables for relevant demographic and educational variables. The variables selected for analysis of covariance were gender, cultural group, current or planned major at university, semesters of university completed when surveyed, and a variable termed "Science and Math Coefficient" that was calculated from the science and math courses' data.

Students' 'cultural group' data was defined as Western (including Europeans, Australians/New Zealanders, and North and South Americans), Asian (including South, Central and East Asians), and Other (all others). Less than 10% of the sample was classified as Other, due to the population characteristics of ISB students. This variable was tested as a covariate as it was considered possible that a student's cultural values and influences, derived from their parents, families, and societies, might influence the dependent variables being studied.

Students' current or planned major at university was categorized as Science (including all engineering-, medicine-, and science-related majors), non-Science (all others), and Undecided. This variable was tested as a covariate as it was expected that students' interests and motivations, as expressed by their chosen university major, might be correlated to the dependent variables being studied.

Students' 'Semesters of University Completed when Surveyed' was defined as stated. This value ranged from 0 for students in the graduating classes of 2013 and 2014 (surveyed while still at ISB), to 7 for students in the class of 2010 (surveyed half way through the 2013-2014 school year). This variable was tested as a covariate as it was expected that students continued study and growth might have an effect on some of the dependent variables being studied.

The final variable, the Science and Math Coefficient, was an attempt to quantify the students' affinity for and ability in science and math, as it was expected that this might have an important effect on the dependent variables being studied. As previously described in Definitions of Terms in Chapter 1, the method used to calculate the Science and Math Coefficient was derived from the science and math courses taken and grades earned during grade 12. It was calculated by summing the products of the course difficulty level and the grade earned for all the science and math courses taken by the student. To illustrate, a student taking IB HL Physics (Difficulty Rating = 2), earning a B+ (Grade Point = 3.3) and also taking IB SL Math (Difficulty Rating = 1), earning a B (Grade Point = 3.0) would be assigned a Science and Math Coefficient of 9.6 (from $[2\times3.3] + [1\times3.0] = 6.6 + 3.0 = 9.6$). Students taking two HL sciences and math, and earning high grades, would have a high Coefficient, while students doing poorly in lower level science and math courses would score a low Coefficient. Students' Science and Math Coefficients ranged from a low of 1.0 to a high of 25.8. The Science and Math Coefficient is assumed to be a measure of a student's affinity for and ability in science.

Collection of Survey Responses

For the survey phase of the data collection, all members of the sample, both the Treatment and the Control Groups, were asked to complete the TOSRA instrument previously described. The survey instrument was administered via a secure online survey format that automatically collected the responses and organized it in an electronic database. In order to increase response rates, emails were sent asking for the students' assistance in filling out the survey, as were follow-up emails for students who had yet to complete the surveys.

Data Analysis

Purpose, Methods and Expected Results

The purpose of the data analysis was to determine the effects of the SRPP on students' science-related attitudes, as measured by the Test of Science-Related Attitudes (TOSRA). The seven attitudes measured were described previously. The method of the data analysis used to accomplish the purpose was to compare the means of the results of the two groups in the study using a multivariate analysis of covariance (MANCOVA) to accommodate the composite variables, with the previously defined Science and Math Coefficient as the covariate. The expected result of the data analysis was a determination of whether there was a significant difference between the two groups in students' science-related attitudes.

Data Preparation and Initial Analysis

The first step was to prepare the data for analysis with a computer-based statistical package. This included converting all text-based data into coded numerical equivalents. For example, for gender, male and female were converted to 0 and 1, as were the other text-based demographic and educational variables, such as Cultural Group and University Major. Similarly, the Likert-scales of the surveys were converted to numerical values on an ordinal scale, then the items in each factor were averaged and reported as the factor score, as described previously.

Once this had been completed, the final prepared data set, including the selected demographic and educational variables and the data from the surveys was analyzed using a computer-based statistical package. The first task was to identify the presence of any ways in which the two groups being studied were different in terms of relevant variables in the demographic and educational data collected. For example, it had to be determined if there were significantly more males than females in the Treatment Group compared to the Control Group. This was accomplished using the t-test for equality of means, in conjunction with Levene's test for equality of variance. Pearson's correlations were also calculated to support the findings. The t-test for equality of means, and the Pearson's correlations, between the Treatment Group and the Control Group were calculated for the variables Gender, Cultural Group, University Major, Semesters at University when Surveyed, and Science and Math Coefficient. The results were presented in tables for easy interpretation.

Analysis of the Data From the Survey Instrument

Turning to the data from the survey instrument, descriptive statistics for the data from the responses were calculated to gain an initial, general understanding of the results. These included number of responses, mean, standard deviation, and percent positive responses for each of the dependent variables measured by the survey. As a further means of grounding the results within a meaningful context, the descriptive statistics from the instrument were compared to results from other studies using the same instrument.

Once a general understanding of the results had been established, the next step was to determine if any of the selected demographic and educational variables had a significant effect on the dependent variables being studied in the survey. T-tests with Levene's tests were conducted to determine if there were any effects. Again, the Pearson's correlations were determined to corroborate the results of the t-tests. The t-test for equality of means, and the Pearson's correlations, between the selected variables and the dependent variables were calculated. The results were presented in tables for easy interpretation.

The results of the tests for differences in the demographic and educational variables between the two Groups, along with the results of the tests for effects of the variables on the dependent variables, were reviewed. These were used to make a decision as to whether a simple Multivariate Analysis Of Variance (MANOVA) would be adequate, or if there was a covariate of sufficient influence to justify its consideration, meaning that a Multivariate Analysis of Covariance (MANCOVA) would be needed. After this determination was made, it was necessary to determine if the assumptions required for the use of these statistical procedures were satisfied. The MANCOVA statistical test, in comparing means, makes certain assumptions concerning the statistical nature of the data sets being compared. The MANCOVA statistical procedure will only return valid results if the data sets upon which it is performed conform to certain characteristics. The data sets tested must exhibit normality, linearity, homogeneity of variance and covariance, and homogeneity of interaction effects (Stevens, 2009, p 218). If the data sets do not satisfy these conditions, then the MANCOVA results may not be reliable. Tests were conducted to determine whether the data sets satisfied the assumptions of normality, linearity, homogeneity of variance and covariance, and homogeneity of interaction effects.

If the assumptions were satisfied, the MANCOVA (or ANOVA if appropriate) was conducted to test if there were significant differences between the two groups in the means of the dependent variables measured by the survey. In cases when the assumptions for use of the MANCOVA were not met, non-parametric comparisons of means, such as the Mann-Whitney test, were performed to determine the effects.

Research Methodology

Objective 2: To determine the effect of the Student Research and Publishing Program on students' understanding of the Nature of Science.

Research Design

A mixed methods design was used for the second objective of the study. This is a procedure for collecting, analyzing and "mixing" quantitative and qualitative data during the research process within a single study (Tashakkori & Teddlie, 2009). For Objective 2, it was expected that, given the depth and complexity of the effects being studied, a mixed methods design would yield a more complete description, a richer understanding of the effects of the SRPP on student outcomes, than would be possible with either quantitative or qualitative methods alone (Creswell & Clark, 2011).

Population

As noted previously, the population for Objective 2 was identical to the population for Objective 1. The definition and details of the two groups in the population, as well as the difference in treatment between the Treatment and Control Groups was also the same as for Objective 1. This was fully described previously and will not be repeated here.

Sample

The sample of the populations for Objective 2 was, again, identical to the sample for Objective 1. The consent form used for Objective 1 covered consent to participate in the full study, including participation in all five Research Objectives. The details were presented in the Sample section for Objective 1, and will not be repeated here.

Research Instrument

The instrument used to address the second objective was the Understanding of Science and Scientific Inquiry (SUSSI) survey. This instrument has been used in the United States, Turkey and China (Liang et al, 2009). It measures student understanding of six of the commonly agreed upon components, or Factors, of NOS, namely:

Factor 1. **Observations and Inferences:** Scientific knowledge development involves a combination of observations and inferences,

Factor 2. **Change of Scientific Laws:** Scientific knowledge is tentative and subject to change,

Factor 3. **Scientific Laws vs. Theories:** Scientific theories and laws are functionally different types of scientific knowledge,

Factor 4. **Social and Cultural Influence on Science:** Scientific knowledge is socially and culturally embedded,

Factor 5. **Imagination and Creativity in Scientific Investigations**: Scientific knowledge development involves human imagination and creativity, and

Factor 6. **Methodology of Scientific Investigation:** Scientific knowledge development involves the use of diverse scientific methods (Liang et al, 2006).

The instrument was developed based on the most recent science education reform documents and existing literature on the nature of science (Liang et al, 2008). The instrument combines both Likert-type items and open-ended questions for each of the six factors, meaning its combined quantitative and qualitative approach is a form of triangulation, which can increase confidence in the findings and help us obtain a fuller understanding of the respondents' views on the nature of scientific knowledge (Liang et al, 2008).

The instrument was piloted by Liang et al in China and the US, revised, then tested further. An expert panel assessed the validity of the Likert-type items, resulting in an agreement rating of between 78% and 100% for all items. The instrument's overall reliability was rated with a Cronbach's Alpha of 0.69. While one of the individual aspects used in this research, scientific methods, had low reliability, the low number of items (4) in each scale means the instrument achieved a satisfactory level of internal consistency (Liang et al, 2008).

In the SUSSI, students are asked to respond to four Likert-type items for each Factor. Each item invites a response on a five-point scale ranging from 'strongly disagree' to 'strongly agree'. The responses were treated in the same way as the responses to the TOSRA survey described in detail for Objective 1. The response to each item was converted to a numerical five-point interval scale, with the four item responses for each factor averaged and interpreted to represent the level of the student's understanding of that aspect of the Nature of Science. The scale used for interpretation of the SUSSI Factor Scores was as follows:

3.51 – 5.00	Informed View
2.51 – 3.50	Transitional View
1.00 – 2.50	Naïve View

Each of the six sections of the SUSSI instrument consisted of four Likert-type items followed by an open-ended question probing the student's understanding of the factor being addressed in that section. The open-ended questions were evaluated using a rubric developed by Miller, Montplaisir, Offerdahl, Cheng, and Ketterling (2010) based on Liang et al (2009). Each response was rated as demonstrating a naïve view, a transitional view, or an informed view of that aspect of NOS, based on the requirements of the rubric. These ratings were converted to a numerical interval scale with 'naïve view' being 1, 'transitional view' being 2, and 'informed view' being 3. Descriptive statistics for the open-ended response ratings, similar to those calculated for the Factor Scores, were calculated and presented. Pearson's correlations between the Factor Scores and the open-ended response ratings were calculated to aid in triangulating between the quantitative and qualitative responses, increasing levels of confidence in the results. Finally, student responses were examined and typical responses representing the range of views were selected and used to further enrich the description of students' understanding of NOS.

The instrument was used with the permission of the author (Appendix B.2). The SUSSI survey instrument is shown in Appendix C.2.

Collection of Data

As previously described, consent to participate in all aspects of the research was obtained for Objective 1, as it was for the needed demographic and educational data. Methods for collecting these were described fully in the Collection of Data section of Objective 1.

Data was collected for the survey phase of Objective 2 in the same way as for Objective 1, previously described. The students were asked to respond to the

SUSSI instrument approximately one week after filling out the TOSRA instrument of Objective 1 in order to reduce chances of student overload and a resulting negative reaction.

Data Analysis

Purpose, Methods and Expected Results

The purpose of the data analysis for Objective 2 was to determine the effects of the SRPP on students' understanding of the Nature of Science, as measured by the Student Understanding of Science and Scientific Inquiry (SUSSI) survey instrument. The method of the data analysis used to accomplish the purpose was to compare the means of the results of the two groups in the study using a multivariate analysis of covariance, with the previously defined Science and Math Coefficient as the covariate. Then the open-ended, qualitative responses were assessed according to the rubric and correlated to the means of the Likert-scale responses. The expected result of the data analysis was a determination of whether there was a significant difference in student understanding of the nature of science between the two groups being studied.

Data Analysis

The data preparation and initial analysis of the Likert-scale data for Objective 2 was identical to the process used for Objective 1. This process was fully described in the Data Analysis section of Objective 1, and will not be repeated here. The analysis of the data from the SUSSI instrument for this objective was also identical to the analysis process of the data for the TOSRA instrument of Objective 1.

This process was fully described in the Data Analysis section of Objective 1, and will not be repeated here.

The qualitative, open-ended responses for each factor were assessed according to the selected rubric. The resulting ratings were compared to the Likert-scale results by calculation of Pearson's correlation to confirm and strengthen the findings. Finally, the qualitative data was analyzed and a range of typical student responses were selected to inform and enrich the understanding of the effect of the SRPP on student understanding of the Nature of Science.

Research Methodology

Objective 3: To determine the effect of the Student Research and Publishing Program on students' experimental research and publishing skills and attitudes.

Research Design

A mixed methods design was used for the third objective of the study, just as for the second objective, and for the same reasons. The rationale for this approach was described in the Research Design section for Objective 2 and will not be repeated here.

Population

The population for Objective 3 is identical to the population for Objective 1. The definition and details of the two groups in the population, as well as the difference in treatment between the Treatment and Control Groups is the same as the population of Objective 1. This was fully described previously.

Sample

The sample of the populations for Objective 3 was, again, identical to the sample for Objective 1. The consent form used for Objective 1 covered consent to participate in the full study, including participation in all five Research Objectives. The details were presented in the Sample section on Objective 1.

Research Instruments

The third objective was addressed through the use of two survey instruments: the Secondary Student Research Skills Self-Assessment (SSRSSA) and the Attitudes toward and Effects of Student Publishing (AESP).

SSRSSA Survey Instrument

The SSRSSA instrument is based on the Undergraduate Research Student Self-Assessment (URSSA), developed by Hunter et al (2009) to measure the affect of summer research experiences of undergraduate students. The URSSA is divided into a number of sections, with each section of items addressing an area of interest to the researchers. Most of the sections are just groupings of related items, to aid in organization. However, the items in each of the first five sections of the instruments were grouped and defined as a factor, with confirmatory factor analysis being performed to confirm the validity of this grouping. These first five sections, consisting of the five defined factors of the URSSA, are described as the core sections. The five-section core of the URSSA survey measures five factors:

Section 1: Factor 1. **Thinking and Working Like a Scientist**: Application of knowledge to experimental research work,

Section 2: Factor 2. **Personal Gains** related to experimental research work, Section 3: Factor 3. **Gains in Skills** related to experimental research,

Section 4: Factor 4. **Attitudes and Behaviors** related to experimental research work, and,

Section 5: Factor 5. **Experience in Science Class** this year. (Hunter et al, 2009).

These five core sections are comprised of a total of 43 Likert-scale type items, with one open-ended response item in Section 5. The rest of the survey is related to undergraduate students' plans and attitudes toward continuing to pursue science in their further studies and careers, as well as other institutional and demographic items. The survey has been methodically developed and validated through a series of pilots and revisions based on expert feedback. Confirmatory Factor Analysis showed that student responses for the core five sections, defined as the five factors described above, met accepted standards for model fit, with some items being eliminated or revised based on this analysis (Hunter et al, 2009). The URSSA was used with the permission of the author, shown in Appendix B.3.

Since the purposes and subjects of this research were not fully aligned with the purposes and subjects of the URSSA instrument, some modification of this instrument was necessary. This involved firstly rewording or refocusing some items in the five core factors of the URSSA to fit a secondary school target audience, with its different experiences and plans. For example, URSSA's use of the phrase "your most recent research experience" was re-phrased as "your lab-based experimental research experiences in your science class this year", "research mentor" was re-phrased as "science teacher," and "plans to enroll in a PhD program in science" was re-phrased to "plans to enroll in a university program in science". In addition, some of the items in the none-core later sections of the URSSA, which were supplemental and optional to the instrument, and would not affect the validity and reliability of the core factors of the instrument (Hunter et al, 2009), were not included, and those sections re-organized.

Removing optional items, aggregating some items into sections and rewording items to make them fit the SRPP students' situation would not be expected to affect the validity of the items of the modified instrument, the SSRSSA (Hunter et al, 2009). However, because the instrument was administered to secondary school students, rather than the undergraduate university students of the original instrument, the SSRSSA was tested for reliability. The instrument was pilot tested with a sample of ISB Science students. The results of the pilot testing of the instrument was subjected to Cronbach's alpha to confirm its reliability.

The final version of the SSRSSA used in this study, shown in Appendix C.3, consisted of the 5 core URSSA sections, rephrased, measuring the five factors of the URSSA, along with three sections addressing other aspects of student outcomes. The topics addressed by each section in the SSRSSA instrument are as follows:

Section 1: Factor 1. **Thinking and Working Like a Scientist**: Application of knowledge to experimental research work,

Section 2: Factor 2. **Personal Gains** related to experimental research work,

Section 3: Factor 3. **Gains in Skills** related to experimental research,

Section 4: Factor 4. **Attitudes and Behaviors** related to experimental research work,

Section 5: Factor 5. **Experience in Science Class** this year,

Section 6. Affect of your experimental research experience on your attitudes toward the future,

Section 7. Motivation to participate in lab-based experimental research experiences in your science class this year, and,

Section 8. General Feedback

Section 1: Factor 1. **Thinking and Working Like a Scientist,** consisted of 8 Likert-type items measuring students' perception of the amount of gain in various aspects of experimental research work. Students are asked to respond to each item on a five-point scale ranging from a first choice of 'no gains' to a middle choice of 'moderate gain' to a final choice of 'great gain'. The response to each item was converted to a numerical five-point interval scale with 1 being 'no gains', 3 being 'moderate gain', and 5 being 'great gain'.

A student's responses to the eight items making up this factor was averaged, with the resulting factor score representing the level of the student's 'Thinking and Working Like a Scientist'. This factor score was interpreted as follows:

4.51 – 5.00	Great Gain
3.51 – 4.50	Good Gain
2.51 – 3.50	Moderate Gain
1.51 – 2.50	Little Gain
1.00 – 1.50	No Gain

Section 2 consisted of eight Likert-type items measuring student perceptions of **Factor 2: Personal Gains related to experimental research work**, while Section 3 consisted of 13 Likert-type items measuring student perceptions of **Factor 3: Gains in Skills related to experimental research**. All of the items in sections 2 and 3 had the same Likert-type choices as the items for Factor 1. The responses to sections 1 through 3 were treated in the same way as the items for the factors in Objective 1. This process was described fully in the Data Analysis section of Objective 1 and will not be repeated here.

Section 4: **Factor 4. Attitudes and Behaviors related to experimental research work**, consisted of eight Likert-type items. Each item asked the students

"How Much" they had felt or done various things related to that factor. The five choices for these items ranged through 'none', 'a little', 'some', 'a fair amount', and 'a great deal'. The factors scores were calculated as with Section 1 and interpreted as follows:

4.51 – 5.00	Very High
3.51 – 4.50	High
2.51 – 3.50	Moderate
1.51 – 2.50	Low
1.00 – 1.50	Very Low

Section 5 consisted of six Likert-type items and one open-ended item addressing **Factor 5. Experience in Science Class this year.** There were four choices for these items: 'poor', 'fair', 'good', 'excellent'. The responses to section 5 were treated in the same way as the items in objective 1. This process was described fully in the Data Analysis section of Objective 1 and will not be repeated here. The factor scores for Factor 5 were interpreted as follows:

3.51 – 4.00	Excellent
2.51 – 3.50	Good
1.51 – 2.50	Fair
1.00 – 1.50	Poor

Because the SSRSSA addressed a very important aspect of the SRPP's predicted effects on student outcomes, an additional analysis of the five factors of the SSRSSA was conducted. For each factor, the items making up the factor were individually analyzed with descriptive statistics being presented for the Treatment and Control Groups for comparison and discussion.

Section 6: **Affect of your experimental research experience on your attitudes toward the future**, consisted of five Likert-type items, and Section 7:

Motivation to participate in lab-based experimental research experiences in your science class this year, consisted of six Likert-type items. The items in these sections had the same choices as those in the TOSRA instrument of Objective 1, ‘strongly disagree’ to ‘strongly agree’. These sections did not form factors, so the items could not be aggregated for analysis. Thus, the item responses were individually analyzed, with descriptive statistics being presented for the Treatment and Control Groups for comparison and discussion.

Section 8: General Feedback, consisted of three open-ended responses seeking further understanding of the effects of participating in research. As with Sections 6 and 7, the items in this section were not aggregated to form a factor. The item responses in these sections were analyzed individually to triangulate the quantitative results and to enrich and deepen understanding of the effects of the SRPP.

Attitudes toward and Effects of Student Publishing Survey Instrument

The second survey instrument used to study Objective 3 was the Attitudes toward and Effects of Student Publishing (AESP) survey. This was an instrument developed by the author for use in this study. It was felt that the SSRSSA, while advantageous since it was a widely used and accepted instrument, focused only on the effects of doing original research. It did not adequately address the publishing aspects of the SRPP.

Since the *Journal of Science* and the publishing of entry-level scientific papers by secondary science students are both crucial and unique parts of the SRPP, an instrument directly investigating the effects of these aspects was necessary to develop a full understanding of the effects of the SRPP on students. The AESP was developed to measure four attributes, namely:

1. Level of and reasons for student interest in publishing,
2. The effects of the possibility of publishing on students' effort during the various aspects of the research process,
3. The effects of publishing a paper in the *JoS* on various aspects of the research process, and,
4. The effects of the SRPP on research participation in university.

The items for each section were drafted, refined, and submitted to a panel of six experts for Item-Objective Congruence (IOC) validation. The IOC form used to validate the instrument is shown in Appendix C.5.

The six experts consisted of four science teachers and two administers at ISB, each with over 15 years of experience in education, and with at least four years of familiarity with the SRPP. One of the teachers was the co-founder of the *Journal of Science*, with seven years direct experience with the SRPP. Two of the teachers had two years direct experience with the SRPP, being the implementing teachers of the Trial Expansion of the SRPP (described more fully in the section addressing Objective 5 in this chapter). Finally, one of the teachers was an expert in English as an Additional Language (EAL), with over 15 years experience in that field, along with familiarity with the SRPP. Each of the experts completed the IOC form and returned it to the author with ratings and comments for each item, and overall approval for the instrument indicated. The feedback from the experts was used to revise and finalize the survey instrument. The reliability of the instrument was then tested through the use of Cronbach's alpha.

The final version of the AESP used in the study consisted of four sections, as detailed above, with a total of 17 Likert-type items and seven open-ended items. As this instrument was designed to gain understanding of the effect of publishing on student outcomes, it was only administered to students in the Treatment Group of the population: students who *were* in the SRPP course.

The first section of the AESP consisted of one Likert-type item asking the student to rate their level of interest in publishing in the *JoS* and one open-response item asking students to explain their answer to the first item. The Likert-type item's five choices ranged from 'not interested at all' to 'extremely interested'. This section was administered to all students in the sample from the Treatment Group.

The second section consisted of a total of ten items. The first eight items addressed the effect of the possibility of publishing on various aspects of the research process, with the first seven items being Likert-type items and the eighth being an open-ended response asking for elaboration on the first seven items. The Likert-type items offered four choices ranging from 'no effect' to 'great effect'. The means of student responses for each item were interpreted as follows:

3.51 – 4.00	Great effect
2.51 – 3.50	Moderate effect
1.51 – 2.50	Little effect
1.00 – 1.50	No effect

The last two items in Section 2 asked students if and how their views of the value of the SRPP had changed since their first enrolling in the program. Section 2 was administered to all students in the Treatment Group.

Section 3 of the AESP instrument was administered to only those students in the Treatment Group sample who had published a paper in the *Journal of Science*. It addresses the effect of the publishing process on various aspects of research and publishing skills. It consists of nine items with the first seven items being Likert-type items, with the same choices as in Section 1, and the last two being open-ended responses asking for elaboration on the first seven items. The responses were analyzed and interpreted in the same manner as those for Section 2, as described above.

The final section of the instrument attempted to determine the effect that the SRPP had on students' participation in scientific research during university. It was only administered to those students in the Treatment Group sample who were at university at the time of taking the survey, those in the graduating classes of 2010 and 2012. This section consisted of two Likert-type items, with the same four choices as in previous sections, asking students to rate the effect of their experience in the SRPP on their level of participation in research at university. The three open-ended items followed up asking for elaboration on the Likert-type item responses.

As different sections were only relevant for certain students (e.g. students who *had* published a paper in the *JoS*, or students who were in university at the time of being surveyed), there were three different versions of the instrument administered to different categories of students. The final version of the AESP, with target students for each section indicated, is shown in Appendix C.7.

Collection of Data

Consent to participate was obtained in Objective 1, as was the demographic and educational data needed. Methods for collecting these were described fully in the Collection of Data section of Objective 1.

Data was collected for the survey phase of Objective 3 in the same way as for Objective 1, which was fully described in the Collection of Data section of

Objective 1. The students were asked to respond to the SSRSSA instrument approximately one week after filling out the SUSSI instrument of Objective 2, with the AESP following a week after that, in order to reduce chances of student overload and a resulting negative reaction.

Data Analysis

Purpose, Methods and Expected Results

The purpose of the data analysis for Objective 3 was to determine the effects of the SRPP on students' experimental research and publishing skills and attitudes. Two survey instruments, the Secondary Science Research Student Self-Assessment (SSRSSA) instrument and the Attitudes toward and Effects of Student Publishing (AESP) instrument, were used to address this objective.

The methods of the data analysis used to accomplish the purpose were, for the SSRSSA Likert-type items, to compare the means of the results of the two groups in the study using a multivariate analysis of covariance, with the previously defined Science and Math Coefficient as the covariate. For the Likert-type item results, descriptive statistics of the results of the Treatment Group were used to interpret the findings. Finally, for the open-ended responses of the two instruments, inductive thematic analysis, more fully described below, was used to triangulate the quantitative results and enrich understanding of the effects of the SRPP on students' research and publishing skills and attitudes.

The expected result of the data analysis was a determination of whether there was a significant difference in student research and publishing skills and attitudes between the two groups being studied, and to enrich the descriptions and understandings of the differences with the qualitative results.

Data Preparation and Analysis

The data preparation and initial analysis of the data for Objective 3 was identical to the process used for Objective 1. This process was fully described in the Data Analysis section of Objective 1. The analysis of the data from Likert-type items from the SSSRSSA instrument for this objective was also identical to the analysis process of the data for the TOSRA instrument of Objective 1.

The AESP survey instrument was only administered to the sample of the Treatment Group, as it was only relevant to students who experienced the SRPP. It was not administered to students in The Control Group, so statistical comparisons could not be made between the two groups. As a result, only descriptive statistics for the AESP, similar to those presented for the first three surveys, were presented and discussed. These included number of responses, mean, standard deviation, and percent positive responses for each of the dependent variables measured by the surveys.

Qualitative Data from the SSRSSA and AESP Survey Instruments

As mentioned, there were a number of open-ended items included in the two survey instruments. This qualitative data was used to triangulate the findings from the analysis of the results of the Likert-type responses, and to enrich and deepen understanding of the effects of the SRPP on students' experimental research and publishing skills and attitudes.

An inductive thematic analysis approach was used with this qualitative data, following the process described by Braun and Clark (2006). The open-ended student responses were collated and organized by question in a database. In order to become familiar with the dataset, all the responses were read through a few times at the start of the process. During these readings, initial impressions were noted.

The next step was 'coding' the dataset. A code is "a feature of the data that appears interesting to the analyst" (Braun & Clark, 2006). The qualitative responses were coded, with important statements, commonly shared opinions, or interesting insights being copied and collated into a separate sheet. For this phase, all relevant points were coded and included for the next phase of analysis.

In the next phase, searching for themes, the codes extracted from the dataset were read through several times, with the goal of seeing patterns in student responses, commonly voiced opinions, or important observations or statements. As themes were identified from this process, the codes extracted from the dataset were arranged into groups representing the emerging themes. It was expected that some new themes would emerge and some initially identified themes would be discarded as inaccurate or unhelpful. As this process was completed, the identified themes were reviewed and analyzed for organization and rank of importance in describing the dataset, making a 'map' of the themes. During this process it was expected that themes would continue to be refined and that new themes could even emerge.

After the thematic analysis was completed, the identified qualitative themes were correlated to the dependent variables measured by the survey instruments to support or refute their findings. Codes (ideas and quotes extracted from the responses) were used in the discussion of the quantitative results to triangulate, enrich, and deepen the understanding of the results of the quantitative data.

Research Methodology

Objective 4: To determine the effect of the Student Research and Publishing Program on students' development of 21st Century Skills.

Research Design

A mixed methods design was used for the fourth objective of the study, just as for the previous objectives, and for the same reasons. The rationale for this approach is described in detail in the Research Design section for Objective 2.

Population

The population for Objective 4 is identical to the population for Objective 1. The definition and details of the two groups in the population, as well as the difference in treatment between the Treatment and Control Groups is the same as the population of Objective 1. This was described fully previously.

Sample

The sample of the populations for Objective 4 consisted of a total of 16 students: eight from the Treatment Group and eight from the Control Group. The sample was obtained by purposive random sampling technique. Lab reports on Independent Research Projects (IRP) from all students participating in the research were obtained. Eight reports from each of the two groups were purposively sampled to be matched pair-wise in terms of the grade received, and to represent a range of grades from high to low.

Research Instrument

A rubric-based instrument was used in helping to address Objective 4. A rubric was designed to assess student's IRP reports for aspects of student gains in 21st Century Skills, as defined by Trilling and Fadel (2009). The rubric was focused on measuring the effects of the SRPP on students' development of 21st Century Skills as evidenced in student lab reports. The rubric was developed and refined by the author, based on accepted principles of rubric development (Tierney & Simon, 2004). The rubric was then submitted to three colleagues experienced in science education and the use of rubrics for comment, with revisions being made based on their comments. The final rubric consisted of nine items, each assessing the level of attainment of one of the 21st Century Skills identified by Trilling and Fadel (2009), as evidenced by the lab report. The nine 21st Century Skills addressed by the rubric are:

- creativity in its experimental design,
- innovation in the implementation of the design,
- problem-solving skills in the conduct of the investigation,
- critical thinking in its analysis and evaluation of the results,
- effective communication appropriate to the purpose,
- collaboration by appropriately placing itself within the context of other's research,
- information literacy in its accessing, evaluating, and using information from a variety of sources,
- ICT literacy if its use of technology to create, organize, and communicate information, and,
- flexibility, initiative, and independence.

Each item asks how much the lab report demonstrates the specified quality, and is assessed on a five-point Likert-scale ranging from 'not at all' to 'a great deal'. The rubric is presented in Appendix D.

Collection of Data

The sample IRP lab reports, to be assessed with the rubric instrument previously described, were obtained from ISB records. As stated earlier, eight reports from each of the two groups were purposively sampled to be matched in terms of the grade received, and to represent a range of grades from high to low. The lab reports were prepared by removing the students' and teachers' names to ensure anonymity. All teacher marks were removed from the reports as well, to reduce chances for bias. Finally, the papers were numbered in a random order.

After being prepared, the sixteen lab reports were sent to be assessed by an expert. The expert has an advanced degree in science, over 20 years of experience teaching science, and over 10 years of experience teaching IB Physics and assessing IB Physics IRP Lab reports. The expert assessed the reports according to the rubric, with the results being used as quantitative data results.

Data Analysis

Purpose, Methods and Expected Results

The purpose of the data analysis for Objective 4 was to determine the effects of the SRPP on students' development of 21st Century Skills, as measured by a rubric-based assessment of students' Lab Reports for their Independent Research Projects. These results were triangulated and enriched by the results of the thematic analysis of the open-ended responses to the SSRSSA and AESP instruments. The method of the data analysis used to accomplish the purpose was to compare the means of the results of the rubric assessment of the two groups in the study, using a t-test. Qualitative data from the thematic analysis was used to further explain and enrich the understandings of the results. The expected result of the data analysis was a determination of whether there was a significant difference in students' development of 21st Century Skills between the two groups being studied.

Data Preparation

The student names and all teacher marks and comments were removed from the sample IRP Lab Reports selected for analysis. The Reports were then assigned random numbers for identification. The outside expert then used the rubric to assess each of the 16 reports in the sample.

The results of the analysis using the Likert-scale were converted to numbers representing an interval scale. The details of the process and interpretation of the conversion will be explained more fully in the next chapter. The data was analyzed through the use of t-tests for equality of means in conjunction with Levene's test for equality of variance, as was done with the results of the surveys. It is recognized that with the low number of responses to each item (N = 8 for each group), levels of confidence in the results of the statistical analysis are an issue. The results of the thematic analysis of the open-ended responses from the SSRSSA and (of Objective 3) were also used in the assessment of the effect of the SRPP on students' development of 21st Century Skills, as a way to triangulate and enrich the understanding of the results of the assessment of the lab reports.

Research Methodology

Objective 5: To develop a Model for Implementation of a Student Research and Publishing Program in Secondary School Science.

Research Design

The methodology for Objective 5 of the research was again a mixed methods approach with quantitative data being gathered from surveys and qualitative data being gathered from surveys and interviews. This method was expected to provide a more complete understanding of the circumstances needed to successfully achieve the objective. However, in Objective 5, the qualitative data, especially the interview results, played a much more central role than in previous objectives, due to the nature of the research objective.

There were two components to the approach for Objective 5. The first component involved the Trial Expansion of the SRPP into Biology and Chemistry. It was felt that the best way to discover the requirements and processes needed to implement the SRPP in a new place was to try it and to study the process. Therefore it was decided to implement the SRPP in the IB Biology and IB Chemistry classes at ISB, and to gather data from the teachers and students involved at the end of the implementation process.

The author, acting as a consultant, assisted an IB HL Biology teacher and an IB HL Chemistry teacher to implement the SRPP into their courses over a period of two years. The trial expansion of the SRPP was begun in August 2012, at the beginning of their IB HL courses, and ended in June 2014, at the end of the two-year courses. The process of the Trial Expansion, along with its effects on students, was studied. The results of this component provided an initial understanding of the process of implementation of the SRPP into a new school.

The second component of the attempt to address Objective 5, building the Model for Implementation, used a series of interviews on the topic of implementing the SRPP in a new school. The results of these interviews, combined with findings from the first component, were used to develop a Model for Implementation of the SRPP.

The Model was expected to consist of an initial section outlining the conditions and requirements needed in a school before the SRPP could be implemented. This was expected to be followed by a series of guidelines indicating how to prepare a school for implementation of the SRPP, the steps needed during the implementation process, and the steps needed to establish the SRPP firmly into the culture of the school in the long term.

The details of the research design will now be described, with the first component, the Trial Expansion being described first, followed by the description of the second component, interviews and finally building and validating the Model for Implementation.

Trial Expansion of the SRPP into Biology and Chemistry

Population

The population for the first component of the research for Objective 5, the Trial Expansion component, included both teachers and students in its study population. The teachers included were the two teachers that were involved in the implementation of the Trial Expansion into IB Biology and IB Chemistry. The population of students involved was a total of N = 186, consisting of two groups.

The first student population group, the Treatment Group, included all students who experienced the Trial Expansion of the SRPP in their two-year IB Biology and Chemistry classes. This included students in IB HL Biology and IB HL Chemistry in the graduating class of 2014. This group had a population of 98 students. The second student population group, The Control Group, consisted of ISB students who experienced the normal science program in their two-year IB Biology or Chemistry programs, but with no exposure to the SRPP and no opportunity to publish their work in the *ISB Journal of Science*. This included students in the IB Biology and IB Chemistry classes of 2013, along with students enrolled in the SL Biology and SL Chemistry classes of 2014. This group had a population of N = 88 students. The student population groups in the Trial Expansion of the SRPP into IB Biology and Chemistry mirror the population groups used in Objectives 1-4 of this study.

Sample

The sample of the two teachers involved in the Trial Expansion included both teachers in the population (N = 2). The sample for the students in the Trial Expansion was similar to the sample for Objectives 1-4. The sample of the total population for the Trial Expansion needed for a 95% Confidence Level in the findings was N = 126. The sample size for a 95% Confidence level for the Treatment and the Control Groups was N = 78 and N = 72, respectively (Krejcie & Morgan, 1970). The sample consisted of all students who consented to participate in the study. Consent was obtained by asking each student in the population to fill out a Consent Form, shown in Appendix A.

Research Instruments

The research instrument used with the two implementing teachers was a semi-structured written interview protocol administered at the end of the Trial Expansion study, in June 2014. The Trial Expansion Teacher Interview was developed according to guidelines described by Creswell (2012) to elicit what the implementing teachers felt had been the strengths and weaknesses of the Trial Expansion process. The instrument addressed both the process of implementation of the SRPP, and the establishment of a culture of research and publishing among the students during the Trial Expansion.

The interview questions were developed and revised by the author. The draft interview protocol was submitted to two colleagues familiar with the SRPP and the Trial Expansion for feedback. The instrument was then revised, based on their feedback, and finalized. The final interview protocol used is shown in Appendix E.

The research instruments used with the students involved in the Trial Expansion component were the same four survey instruments (TOSRA, SUSSI, SSRSSA, and AESP) used in the first part of the study (Objectives 1-3) with the students in the established SRPP in Physics. These instruments, their administration, and their analysis were fully described and discussed in the first part of this chapter, so will not be described in detail here.

Collection of Data

The Trial Expansion Teacher Interview instrument was administered to the two implementing teachers in June 2014. The teachers were requested to submit written responses to the interview items.

The process for collecting data from the two groups of students involved in this part of the study was identical to that used for collecting data from the students in the first part of the study. All members of the populations of both groups (along with their parents for those under 18) were requested to fill in a participation consent form. Those who consented to participate were asked to respond to the four online survey instruments used in Part 1 over a period of several weeks near the end of the school year. The responses were recorded in an online database that was downloaded and subjected to statistical analysis when all responses were complete. (A more detailed description of the process used can be found in the first part of this chapter addressing Objectives 1-3.)

Data Analysis

Purpose, Methods and Expected Results

The purpose of the data analysis for Objective 5 was to develop a validated Model for Implementation of the SRPP in a new school. There were two main components to the method of the data analysis used to address this objective. The first component consisted of conducting a two-year Trial Expansion of the SRPP into Biology and Chemistry at ISB. After the Trial Expansion, interviews were conducted with the implementing teachers to determine their perceptions of the strengths and weaknesses of the Trial Expansion process. The results of the interviews were analyzed using inductive thematic analysis. The students participating in the Trial Expansion responded to the same survey instruments used in the first part of the study. Statistical analysis, including descriptive statistics and multivariate analysis of covariance was used, in the same way as in the first part of the study.

The expected result of this component of the data analysis was an initial understanding of the conditions and challenges of implementing the SRPP in other programs or schools. The results of this component of the data analysis were expected to be used to inform the development of the Model for Implementation of the SRPP in other schools.

Data Analysis

The Trial Expansion Teacher Interview responses were analyzed using inductive thematic analysis (Braun & Clark, 2006), in the same way as the qualitative survey data was in the first part of this study. The inductive thematic analysis process was described in detail previously, so will only be summarized here.

The interview responses were organized by question in a database and read through several times for the purpose of familiarization and gathering overall initial impressions. The dataset was then coded, picking out relevant or important ideas, observations and insights. The codes were then analyzed and organized into themes, which were then analyzed for patterns and over-arching principles.

The result of the thematic analysis of the Trial Expansion Teacher Interview was expected to provide insights into the strengths and weaknesses, successes and failures, of the attempted Trial Expansion of the SRPP.

The second aspect of the Trial Expansion study involved the survey responses of the two groups of students described previously. The instruments used here were the same as those used in Objectives 1-3, and the defining conditions of the two groups were also the same. The data analysis process was therefore also the same as that used to analyze the survey responses for Objectives 1-3 of the study. This was explained in detail in the first part of this chapter, so will only be summarized here.

The demographic and educational data from the sample, along with the survey responses, were prepared for analysis. The demographic and educational data was analyzed for the need to use covariates, in the same way as for Objectives 1-3. The data sets were checked for the satisfaction of the assumptions required, and then subjected to MANCOVA analysis for each of the surveys. The results of the MANCOVA were presented and discussed, along with the findings from the Trial Expansion Teacher Interview, for implications in building the Model of Implementation of the SRPP.

Research Design

Building the Model for Implementation of the SRPP

Population

The population for the second component of Objective 5 included both adults and students. The adult population of the study included the co-founder of the *Journal of Science* (N = 1), three ISB High School administrators (N = 3), two ISB High School IB Physics teachers (not including the author) (N = 2), and the two teachers involved in the Trial Expansion component (N = 2). The student population of this component of the study included all ISB IB Physics students in the SRPP (the Treatment Group from the first part of the study) (N = 118).

Sample

The sample of the adults included all in the study population of component 2. The sample consisted of the co-founder of the *Journal of Science* (N = 1), the three ISB High School administrators (N = 3), the two ISB High School IB Physics teachers (not including the author) (N = 2), and the two teachers involved in the Trial Expansion component (N = 2). This gave a total adult sample of eight (N = 8).

The students selected for the interviews in component 2 were selected by purposive random sampling technique. The sample consisted of a total of six students (N = 6), being selected as follows:

- Two students randomly chosen from the population of students who were currently studying at ISB (graduating class of 2014) and had *not* published a paper in the *JoS* (N = 2),
- Two students randomly chosen from the population of students who were currently studying at ISB and *had* published a paper in the *JoS* (N = 2),
- One student randomly chosen from the population of students who had already graduated from ISB (was currently studying at university) and had *not* published a paper in the *JoS* (N = 1), and
- One student randomly chosen from the population of students who had graduated from ISB (currently studying at university) and *had* published a paper in the *JoS* (N = 1).

The purpose of this selection method was to include as wide a range of experiences and perspectives in as small a sample as possible.

Research Instruments

A semi-structured oral interview was the instrument used for this part of the research. A series of open-ended interview questions designed to address the various aspects of implementing the SRPP in a new school was developed. The interview instruments developed for the various groups consisted of between 9 and 14 questions and focused on gathering perceptions of the benefits and challenges of implementation of the SRPP from each of the three groups interviewed.

Considering the very different characteristics of the members of the interview sample, the questions included in the interview protocol were adapted to the characteristics of the group that was being interviewed. The questions for each group were different in focus and form as appropriate to the age and perspective of the interviewees, while still being addressed to understanding the perceived challenges and benefits of implementation of the SRPP. For example, the first question of the interview for students was "What do you think about doing IRP's?" This question was only asked of students. The first question for teachers and administrators was "What you think about the Research and Publishing program we have here at ISB?" This question was not asked of students. Some questions were asked of both groups, such as, "What do you think are the overall characteristics needed by a high school in order to successfully implement a Student Research and Publishing program?"

Versions 1 and 2 of the interview protocol were designed for the students in the sample group. Version 1 was for students who had *not* published a paper in the *JoS* and Version 2 was for students who *had* published. Version 3 of the interview protocol was for the adults (four teachers, three administrators, and the co-founder of the *JoS*) in the sample. All versions of the interview protocol are presented in Appendix F.

Similar to the development process for the Trial Expansion Teacher Interview instrument previously described, the interview items were developed and revised by the author. The draft interview protocol was then sent to two colleagues familiar with the SRPP for feedback. The protocol was then revised, based on their feedback, and finalized. The interview protocols used are shown in Appendix F.

Collection of Data

In accordance with interviewing guidelines, the interviews were conducted by a colleague of the author who was unknown to the interviewees, to avoid the possibility of the relationship between the author/interviewer and the interviewee skewing responses (Creswell, 2012). The interviews were conducted with the 14 members of the sample during March and April of 2014. The interviews were limited to no more than one hour, to minimize demands on both the interviewer and interviewee.

The interviews with members of the sample currently at ISB were conducted face to face, either individually or in pairs, depending on scheduling limitations. The interviews with the two former students in the sample who were at university were conducted via Skype. The interviews were recorded and the recordings were transcribed in full for subsequent analysis.

Data Analysis

Purpose, Methods and Expected Results

To review, the purpose of the data analysis for Objective 5 was to develop a validated Model for Implementation of the SRPP in a new school. There were two main components to the method of the data analysis used to address this objective. The first component consisted of conducting a two-year Trial Expansion of the SRPP into Biology and Chemistry at ISB and was described in the previous section.

For the second component of the approach to this objective, interviews were conducted with a range of experts and participants in the established SRPP at ISB. The interview transcripts were analyzed using inductive thematic analysis, with the results used to build a draft Model for Implementation. The draft Model was subject to validation by experts and the expert feedback used to revise and finalize the Model.

The expected result of the data analysis was a validated Model for Implementation of the Student Research and Publishing Program in a new school. The Model was expected to be structured into several sections addressing the various steps needed to successfully implement the SRPP. Firstly, the conditions and characteristics of a school necessary for successful implementation of the program needed to be identified, to enable schools to make an informed decision to adopt the program or not. In the next section, it was expected to address the steps required for preparing the administrative structures, curricula, teachers and students for implementation of the SRPP. The last section was expected to address the actions needed to introduce the program in the first years, and then establish it as part of the school culture in the long term.

Data Analysis

The Interview responses were analyzed using inductive thematic analysis (Braun & Clark, 2006), in the same way as the qualitative survey data was for Objective 3. The inductive thematic analysis was described in detail previously, so will only be summarized here.

The interview responses were organized by question in a database and read through several times for the purpose of familiarization and gathering overall initial impressions. The dataset was then coded, picking out relevant or important ideas, observations and insights. The codes were analyzed, summarized, and organized into themes, which were then analyzed for patterns and over-arching principles. The result of the thematic analysis of the interview was expected to provide insights into student, teacher, and administrator views on the benefits, conditions, challenges, and methods needed for implementation of the SRPP in other schools.

The findings from both components 1 and 2 were then studied and used to develop a draft Model for Implementation of the SRPP. This draft Model was then submitted to experts, with a range of experience, for validation and refinement. Four classes of expert validators were chosen, as follows:

1. Outside experts with advanced degrees and more than 20 years of experience in science education, educational leadership, and educational program development and reform (N = 4),
2. ISB High School administrators with over 10 years of experience in education and having familiarity with the SRPP (N = 3),
3. ISB High School science teachers (including all who participated in the interviews) with at least 15 years of experience and familiarity with the SRPP (N = 4),
4. The six ISB students who participated in the interviews and were therefore assumed to have thought about the issues of implementation of the SRPP and could provide feedback from the student perspective on the draft Model of Implementation (N = 6).

The validation form for the draft Model for Implementation of the SRPP invited ratings and comments on the Model in each of four areas: Precision, Effectiveness, Sufficiency, and Feasibility. The form also asked for an overall approval of the Model. The validation form was developed with the assistance of Dr. Sangob Laksana (personal communication).

The feedback from the experts given in the validation form for the Model for Implementation was subjected to inductive thematic analysis, in the same way that the previous qualitative responses were analyzed. The analysis process was previously described in detail, and will not be repeated here.

The findings of the thematic analysis of the expert feedback were used to revise and refine the Model for Implementation, resulting in a final Model for Implementation of the Student Research and Publishing Program in Secondary School Science. This final, validated Model was informed by the findings from the established SRPP from Objectives 1-4, along with the findings of the Trial Expansion of the SRPP, the findings from the interviews designed to aid in the building of the model, and the experts' validation feedback.

Review of the Research Design

Before starting the analysis of the data, it would be helpful to review the research design for this study.

Review of Research Design for Objectives 1-4

Objectives 1-4 studied the effects of the SRPP on four aspects of student outcomes. Two groups of students who completed IB Physics courses at ISB were compared. The first group, Group 1, was the Treatment Group. This group enrolled in the standard ISB science program in grades 9 and 10, and then enrolled in the IB Physics course ***with an established SRPP integrated into the course*** in grades 11 and 12. The second group, Group 2, was the Control Group, used for comparison. This group enrolled in the standard ISB science program in grades 9 and 10, and then enrolled in the IB Physics course ***with no SRPP*** in grades 11 and 12.

The standard ISB Science program in grades 9 and 10, experienced by both the Treatment and the Control Groups, is an inquiry-based program which leads students from confirmation inquiry to open inquiry, with independent research projects required. The standard ISB Science program covers topics in Biology, Chemistry and Physics typical of North American grades 9 and 10 Science.

The IB Physics course, experienced by both the Treatment and Control Groups, is the standard course mandated by the International Baccalaureate Organization (IBO) covering prescribed theoretical content and laboratory components, with internal laboratory assessments and an external exam.

The SRPP, the focus of this research, is the experimental treatment, the difference between the Treatment and the Control Groups. The SRPP focuses students on a simplified three-part model of the scientific process. The program requires students to conduct authentic, original scientific research, with the possibility of publishing their findings in an entry-level scientific journal. The SRPP and the research design are described in more detail in chapters 1 and 3.

Review of Research Design for Objective 5

Objective 5 aims to develop a Model for Implementation of the SRPP in other schools. The process was approached in two phases, a Trial Expansion of the SRPP into Biology and Chemistry at ISB, and the process of developing and validating the Model itself.

Trial Expansion of the SRPP. A study of the effect of the Trial Expansion on student outcomes provided the main focus of the Trial Expansion into Biology and Chemistry. This part of the study was conducted similarly to Objectives 1-3. The other part of the study of the Trial Expansion was a written interview protocol, administered to the two participating teachers, which elicited their views on the strengths and weaknesses of the Trial Expansion process. The interview responses were subjected to inductive thematic analysis. The results of both parts of the study were used to inform the building of the Model.

Building the Model for Implementation of the SRPP. The results of the analysis of the Trial Expansion were used as a starting point of the building of the Model. This was supplemented by a series of interviews conducted with students, teachers, and administrators familiar with the SRPP. The interview focused on the topic of the values and benefits of the SRPP, and the conditions, challenges, and process of implementing the SRPP in another school. These interviews were subjected to inductive thematic analysis, with the results of the analysis, informed by the findings from the Trial Expansion, being used to develop a draft of the Model. The Model was then subjected to experts for validation. These experts were from a range of fields and had a range of experience,. The feedback from the validation experts was used to revise the Model, resulting in a final, validated, Model for Implementation of the SRPP in other schools. The research design for Objective 5 is described in more detail in chapter 3.

Table 3.2: Summary of the Research Process

Research Objective	Source of Data or Sample	Data Collection Method or Research Instrument	Data Analysis	Expected Outcomes
1. To determine the effect of the SRPP on students' science-related attitudes.	1. ISB records. 2. Students in IB Physics with SRPP AND Students in IB Physics without SRPP.	1. Demographic and educational data from ISB records. 2. TOSRA online survey.	Descriptive Statistics and MANCOVA.	Determination of significance of differences between groups
2. To determine the effect of the SRPP on students' understanding of the Nature of Science.	1. ISB records. 2. Students in IB Physics with SRPP AND Students in IB Physics without SRPP .	1. Demographic and educational data from ISB records. 2. SUSSI online survey	1. Descriptive Statistics and MANCOVA (for quant. data). 2. Inductive Thematic Analysis (for qual. data)	Determination of significance of differences between groups
3. To determine the effect of the SRPP on students' experimental research and publishing skills and attitudes.	1. ISB records. 2. Students in IB Physics with SRPP AND Students in IB Physics without SRPP.	1. Demographic and educational data from ISB records. 2. SSRSSA & AESP online surveys.	1. Descriptive Statistics and MANCOVA (for quant. data) 2. Inductive Thematic Analysis (for qual. data)	Determination of significance of differences between groups
4. To determine the effect of the SRPP on students' development of 21st Century Skills.	1. ISB records. 2. Students in IB Physics with SRPP AND Students in IB Physics without SRPP.	1. Copies of IRP Lab Reports from ISB records. 2. Qualitative responses from SSRSSA & AESP online surveys.	1. Rubric-based Assessment of Lab Reports 2. Inductive Thematic Analysis (for qual. data from SSRSSA & AESP)	Determination of significance of differences between groups
5. To develop a Model for Implementation of a Student Research and Publishing Program in Secondary School Science.	1. ISB records. 2. Students in IB Biology & Chemistry with SRPP (Trial Expansion of SRPP group) AND Students in IB Biology & Chemistry without SRPP. 3. ISB Teachers Implementing Trial Expansion of SRPP. 4. ISB Administrators, Teachers, and Students familiar with SRPP. 5. Educational Experts & ISB Admin, Teachers & Students familiar with SRPP.	1. Demographic and educational data from ISB records. 2. TOSRA, SUSSI, SSRSSA, & AESP online surveys. 3. Trial Expansion Teacher Interview: written-response interview. 4. Model Development Interview: oral interview. 5. Draft Model for Implementation & Validation Form.	1. Descriptive Statistics and MANCOVA (for quant. data) 2. Inductive Thematic Analysis (for qual. data) 3. Inductive Thematic Analysis for Trial Expansion Teacher Interview, Model Development Interview, & Validation Form responses.	Validated Model for Implementatio n of the SRPP in other secondary schools.

CHAPTER IV

RESEARCH FINDINGS

This chapter will present the data analysis and research findings of this investigation. The chapter will be organized into two parts. The first part is a study of the effects of the established SRPP in Physics on four aspects of student outcomes. This part includes the analysis for Objectives 1-4. As a mixed methods study, the data includes both quantitative and qualitative aspects. The quantitative data, the foundation of the first part, will be analyzed with a variety of appropriate statistical methods. The qualitative data will be analyzed thematically or with rubrics as appropriate. The results of the qualitative analysis will be used to triangulate, extend and enrich understanding of the quantitative results of the first four objectives. The second part of the study focuses on developing a Model for Implementation of the SRRP in other schools, Objective 5. Qualitative data will be used as the primary means of addressing the research question in Objective 5, with quantitative data playing a lesser role.

Overview of the Analysis Process

Analysis for Objectives 1-4: Overview

The first part of the study addressed the first four research objectives, looking at the four different aspects of the effects of the established SRPP on student outcomes.

Objective 1, to determine the effect of the SRPP on students' science-related attitudes, was addressed through the use of the Test of Science-Related Attitudes (TOSRA) survey instrument. The survey was administered to two groups of students: those who were enrolled in the SRPP-based Physics course and those who were enrolled in an IB Physics course with no SRPP. The results of the surveys were analyzed using multivariate analysis of covariance to determine the significance of any differences between the means of the groups.

Objective 2, to determine the effect of the SRPP on students' understanding of the Nature of Science, was addressed by the use of the Student Understanding of Science and Science Inquiry (SUSSI) survey instrument. The instrument was administered to the same two groups, and the results subjected to an analysis similar to that used for Objective 1. The SUSSI also included qualitative data that was scored using a rubric developed by Miller et al (2010) and used to triangulate and enrich the findings of the quantitative data.

Objective 3, to determine the effect of the SRPP on students' experimental research and publishing skills and attitudes, was addressed through the use of two instruments: the Secondary Student Research Skills Self-Assessment (SSRSSA) and the Attitudes toward and Effects of Student Publishing (AESP). These instruments produce both quantitative and qualitative data. The quantitative data was analyzed in the same manner as for the previous objectives. The qualitative data was approached with an inductive thematic analysis and the results used to triangulate, enrich and extend the understandings from the quantitative results.

Finally, Objective 4, to determine the effect of the SRPP on students' development of 21^{st} Century Skills, was addressed through a comparative, rubric-based analysis of a purposively selected sample of independent research lab reports from the two groups. It was also addressed with relevant qualitative results from the SSRSSA and AESP instruments of the previous objective.

It was hoped that this four-faceted, mixed methods approach to the study would yield a rich, full understanding of the overall effects of the SRPP on a range of students' abilities and attitudes. It was expected that this approach would result in a fairly complete picture of the SRPP's benefits and limitations, of its strengths and weaknesses.

Analysis for Objective 5: Overview

The second part of the study addressed the fifth research objective, to develop a Model for Implementation of the Student Research and Publishing Program in Secondary School Science. Two main approaches were used in the attempt to gain the knowledge and understanding necessary to develop a valid Model.

Firstly, a Trial Expansion of the SRPP into Chemistry and Biology was conducted between August 2012 and June 2014. Two approaches were used to gather information from the Trial Expansion to aid in the development of the Model. Firstly, the teachers involved in the implementation of the Trial Expansion were interviewed at the end of the process to determine their views of the strengths and weaknesses of the Trial Expansion attempt. The interviews were subjected to analysis to extract themes and key findings. Secondly, the four survey instruments used in the first part of this study were administered to students in the Trial Expansion, and analyzed in the same way to determine the effects of the Trial Expansion on the three aspects of students' attitudes and abilities addressed in Objectives 1-3.

The second, and more important, part of addressing research Objective 5 was an interview conducted on the topic of how to implement the SRPP in another school. This interview was conducted with a series of expert teachers, administrators, and students who had familiarity or experience with the SRPP. The interviews were transcribed, with the transcripts being subjected to inductive thematic analysis to determine the themes and key findings of the interview results.

The results of the interview analysis were used, in conjunction with the findings from the Trial Expansion and the author's own experience, to develop a draft of the Model for Implementation. The draft Model was sent for validation to a group of validators including outside educational experts, administrators, teachers and students who had experienced the SRPP.

Upon validation, the comments of the validators were integrated into the Model to improve and refine it, resulting in the Model for Implementation of a Student Research and Publishing Program in Secondary School Science presented at the end of this chapter.

Population, Samples, and Initial Data Preparation for Objectives 1-4

Because of the complexity of humans, schools, and the educational endeavor, it was decided to look at four aspects of the effects of the SRPP, using a mixed methods approach, with four objectives defined. The first three objectives employed a series of four student survey instruments with both Likert-type and open-ended questions, along with analysis of a range of other relevant data. The fourth objective used a rubric-based analysis of a sample of lab reports to address the question of students' development of 21st Century Skills.

Population and sample numbers and characteristics. For the first three objectives, the population, sample numbers and characteristics of the sample were the same for each objective. Students enrolled in IB Physics at ISB in the classes of 2010-2014 were invited to participate in the study. Students in the classes of 2010, 2012, and 2014 were enrolled in an IB Physics course implementing the

SRPP. Students in the classes of 2011 and 2013 were enrolled in a normal IB Physics course that did **not** implement the SRPP as part of the course. The reasons for these selections were discussed previously. The numbers of students in the populations of each of the groups, along with the number of students who consented to participate in the sample studied, is presented in Table 4.1, below. The total population was N = 166. The total sample from that was N = 144, which was greater than the N = 116 sample size needed to have a 95% confidence level in the results (Krejcie & Morgan). It must be noted that the sample for the Control Group, Students Not in the SRPP, was smaller and only at the 90% confidence level.

Due to the fact that existing populations were used in this study, neither the size of the populations nor the samples were equal. There was no way to avoid this. The 100% participation rate for the 2014 population was due to the fact that this population was currently enrolled in the author's course when the surveys were administered. The high participation rates of the other "In SRPP" populations is due

Table 4.1: Population and Sample numbers by year and SRPP status.

Year of Graduation (SRPP Status)	Dates Surveyed	Population N	Sample N	Percent of Pop. in Sample
2010 (In SRPP)	Nov-Dec, 2013	41	38	93
2011 (Not in SRPP)	Nov-Dec, 2013	22	14	64
2012 (In SRPP)	Nov-Dec, 2013	38	35	92
2013 (Not in SRPP)	April-May, 2013	26	18	69
2014 (In SRPP)	April-May, 2014	39	39	100
Total (In SRPP)		118	112	95
Total (Not in SRPP)		48	32	67
Total		166	144	87

to the fact that they were former students of the author, and thus were more likely to agree to a request to participate in the study.

For Objective 4, a sub-sample of 16 of the students who consented to participate in the study was obtained through purposive random selection. Eight students from each group whose grades on their IRP Lab Reports were matching and with grades representing a wide range were selected.

Data used in the study for Objectives 1-4. As mentioned in the previous chapter, a wide variety of data was gathered in order to develop as rich an understanding of the effects of the SRPP as possible. Demographic data, along with science and math course grades for the last year of high school, was obtained from the school. Permission of the school, the parents, and the students was obtained for this. For each of the four survey instruments, student responses were downloaded from the online database. Copies of Independent Research Project (IRP) lab reports from a sample of the participants were also obtained from ISB records.

Preparation of the data for Objectives 1-4. Student demographic and course data were converted into numerical values with appropriate coding. The course data were converted into numerical data based on course subject (physics, biology, chemistry, math) and difficulty level (IB Higher Level = 2, IB Standard Level = 1, non-IB = 0). Course grades were converted from a percentage to a grade point using the scale of 4.0 to 0.0 for A to F grades.

It was expected that a students' affinity for and ability in science and math would be an important predictor for many of the characteristics that were measured by the surveys. Therefore, a Science and Math Coefficient was defined and calculated for each student. The Science and Math Coefficient was calculated by summing the product of the course difficulty level and the grade earned for all the science and math courses taken by the student. The calculation was described in detail in Chapter 1.

Likert-type responses from the surveys were converted to numerical scales (1-5 or 1-4 as appropriate) and entered into a database. Average responses and factor scores were calculated as appropriate. Open-ended responses from the surveys were organized by student and item number for future analysis. All numerical data for all participants was entered into a computer-based statistical package. The sample of IRP lab reports, used in Objective 4, was prepared for analysis by removing identifying information and teacher comments and grades, and randomizing the sample. With the data prepared and ready, analysis was begun for Objectives 1-4.

Data Analysis

Objective 1: To determine the effect of the SRPP on students' science-related attitudes.

To review, the purpose of the data analysis for Objective 1 is to determine the effects of the SRPP on students' science-related attitudes, as measured by the Test of Science-Related Attitudes (TOSRA). The Independent Variable is 'Participation in the SRPP', with Group 1, the Treatment Group, enrolled in an IB Physics course with the SRPP integrated into the course, and Group 2, the Control Group, enrolled in an IB Physics course with no SRPP. The Dependent Variables for Objective 1 are students' Science-Related Attitudes, as measured by the TOSRA survey instrument. The method of the data analysis used to accomplish the purpose is to compare the means of the results of the two groups in the study. This was accomplished using a multivariate analysis of covariance, with the previously defined Science and Math Coefficient as the covariate. The expected result of the data analysis is a determination of whether there is a significant difference between the two groups in students' science-related attitudes.

The TOSRA instrument has been well tested for reliability and validity, as previously described, and no changes were made to the instrument for this study, so no reliability or validity testing was done here.

Descriptive Statistics

The results of the TOSRA Likert-type responses for students who were in the SRPP are presented in Table 4.2. Each of the five items in each factor was rated on a scale from "Strongly Agree" (5) to "Strongly Disagree" (1). Thus, a factor score of 4.0 or above indicates a positive attitude towards that factor, while a score of 2.0 or below indicates a negative attitude towards that factor (Fraser, 1981). The scale used to interpret the group means of the factor scores was defined in Chapter 3 as follows:

4.51 – 5.00	Very Positive
3.51 – 4.50	Positive
2.51 – 3.50	Neutral
1.51 – 2.50	Negative
1.00 – 1.50	Very Negative

Factor S: Social Implications of Science, showed a mean of 4.10, indicating a positive attitude towards this factor, with 69% of students responding "Agree" or "Strongly Disagree" with the items in this factor. **Factor N: Normality of Scientists** was lower, with a mean of 3.46, indicating that, on average, students were neutral (but nearly in the positive range) towards the idea that scientists are "normal people", with only 18% of students showing a positive attitude here. **Factor I: Attitude to Scientific Inquiry** was slightly higher, with a mean in the positive

Table 4.2: TOSRA results for students who participated in the SRPP

TOSRA Factor	N	Mean	SD	Interpre -tation	Percent Responses >= 4
Combined Score	112	3.79	0.39	Positive	29
Factor S: Social Implications of Science	112	4.10	0.47	Positive	69
Factor N: Normality of Scientists	112	3.46	0.47	Neutral	18
Factor I: Attitude to Scientific Inquiry	112	3.71	0.60	Positive	40
Factor A: Adoption of Scientific Attitudes	112	4.14	0.45	Positive	75
Factor E: Enjoyment of Science Lessons	112	4.04	0.59	Positive	62
Factor L: Leisure Interest in Science	112	3.41	0.76	Neutral	27
Factor C: Career Interest in Science	112	3.66	0.77	Positive	40

range, and with 40 % reporting a positive attitude. **Factor A: Adoption of Scientific Attitudes** also showed a mean in the positive zone, 4.14, with 75% of students reporting a positive response indicating their adoption of scientific attitudes, as did **Factor E: Enjoyment of Science Lessons** with a mean of 4.04 and 62% positive response here. Finally, **Factor L: Leisure Interest in Science** (3.41) and **Factor C: Career Interest in Science** (3.66) both showed that students, on average, had a positive attitude toward these two factors, with positive responses of 27% and 40% of students respectively.

While interesting, without a context these results mean little. As explained earlier, one of the reasons that existing instruments were chosen for use in this study, was to allow the results of this study to be placed in a wider context of research results from other studies. The results of the current study were compared to three studies. The first study (Fraser, 1981) was carried out on 1,337 students in Australian middle schools. The second (Jewell, 2011) administered an instrument including four of the seven TOSRA factors to 114 US High School students, while the third (Welch, 2010) administered an instrument including a different combination of four of the seven TOSRA factors to 99 US High School students. The comparison of these studies with the current study showed that SRPP students showed similar attitudes toward science, within standard deviations, as compared to the students in the other studies, on several of the factors in these three studies, in spite of their differences in age, school, and country. Interestingly, SRPP students showed scores that were higher than the others by more than the standard deviation on four factors: Social Implications and the last three factors. While it is difficult to know the reasons, it is suggested that these differences are due to the fact that the SRPP students have all elected to enroll in IB Physics, indicating a pre-disposed affinity and talent for math and science, which could be expected to result in higher scores on these factors. While no statistical tests for significant differences can be done between these groups, it is helpful to compare these results as a way of placing the results of the current study within the context of other research in the field.

Having reported the results of the TOSRA instrument for SRPP participants, and placed them in the context of other research, it is now time to address the relevant research question: How does the SRPP affect students' science-related attitudes, as measured by this instrument? This will be done by comparing the TOSRA results of SRPP participants in the IB Physics program at ISB with students in IB Physics classes at ISB that did not participate in the SRPP.

While the number of respondents not in the SRPP (N = 31) was much lower than the number that were in the SRPP (N = 112), due to the characteristics and limitations of the available populations, it is quickly obvious that there is not a large difference between the two groups for any of the factors. All seven TOSRA factors except factor N, as well as the combined TOSRA score, do show the mean response of students in the SRPP to be a little higher than those not in the SRPP, but the difference is small for most of the factors. There is a larger difference (about half the SD) in Factor E: Enjoyment of Science Lessons, with the SRPP students being higher. This pattern is repeated when looking at the proportion of respondents who answered positively for each factor. In order to understand the significance of these differences, a multivariate analysis of variance (MANOVA) must be performed on the data.

4.3: TOSRA Results from the Control and Treatment Groups, students **not** participating in the SRPP and students participating in the SRPP in IB Physics at ISB.

TOSRA Factor	**Student SRPP Status**	**N**	**Mean**	**SD**	**Percent Responses >= 4**
Combined Score	Not in SRPP	31	3.69	0.37	19
	In SRPP	112	3.79	0.39	29
Factor S: Social Implications of Science	Not in SRPP	31	3.95	0.46	52
	In SRPP	112	4.10	0.47	69
Factor N: Normality of Scientists	Not in SRPP	31	3.50	0.50	26
	In SRPP	112	3.46	0.47	18
Factor I: Attitude to Scientific Inquiry	Not in SRPP	31	3.61	0.69	32
	In SRPP	112	3.71	0.60	40
Factor A: Adoption of Scientific Attitudes	Not in SRPP	31	4.13	0.52	74
	In SRPP	112	4.14	0.45	75
Factor E: Enjoyment of Science Lessons	Not in SRPP	31	3.74	0.64	39
	In SRPP	112	4.04	0.59	62
Factor L: Leisure Interest in Science	Not in SRPP	31	3.31	0.63	16
	In SRPP	112	3.41	0.76	27
Factor C: Career Interest in Science	Not in SRPP	31	3.59	0.66	26
	In SRPP	112	3.66	0.77	40

Testing for Covariates

Given the characteristics and limitations of the available populations of the SRPP participants and non-SRPP participants groups, it is important to determine if there are any uncontrolled, outside variables that might have an impact on the results that show significant difference between the groups. To accomplish this, between-group t-tests, along with Levene's test for Equality of Variance, were performed for the variables of Gender, Cultural Group, Planned University Major (science/non-science), Science and Math Coefficient (defined previously), and Semesters of University Completed when Surveyed (defined previously). These variables were chosen as it was hypothesized that they might have an effect on the dependent variables.

The results of these tests are shown in Table 4.4. It is clear that the only variable which shows a significant difference in means between the populations of the two groups is the Semesters of University Completed when Surveyed.

Table 4.4: Tests for difference in means between groups for uncontrolled variables.

Factor Tested	Levene's Test for Equality of Variances (Sig.)	Equality of Variance	t-test for Equality of Means (Sig.)
Gender	0.46	Assumed	0.72
Cultural Group	0.44	Assumed	0.69
University Major	0.07[a]	Not Assumed	0.26
Science & Math Coefficient	0.81	Assumed	0.21
Semesters of Uni when Surveyed	0.41	Assumed	0.02*

[a] Equality of Variance cannot be assumed.
* Significant at the $p < 0.05$ level.

After completing these tests, the exploratory investigation into the TOSRA results was continued by looking at the correlations between these variables, as well as between these variables and the dependent variables, the TOSRA factors, if any. This was done in order to better understand the influences affecting the results and to determine which of these factors it might be necessary to use as a covariate in the multivariate analysis of variance of the differences between groups. The resulting Pearson's correlation calculations are shown in Table 4.5.

A number of interesting relationships can be seen in Table 4.5. Firstly, the result of the t-tests in Table 4.4 are supported, as only Semesters of University when Surveyed has a significant positive correlation with SRPP Participation status(although Science and Math Coefficient does have a weak, though not significant, positive correlation of 0.11). Looking at relationships between the uncontrolled variables, it is unsurprising, though unfortunate, to note that there is a

Table 4.5: Pearson's Correlations between the uncontrolled variables and the two SRPP participation status groups

Variables	Gender	Cultural Group	University Major	Science & Math Coefficient	Semesters of Uni When Surveyed
SRPP Participation Status	-0.03	-0.033	0.12	0.11	.20*
Gender		-0.001	.22*	0.061	.20*
Cultural Group			0.094	-0.071	0.067
University Major				.25**	.18*
Science & Math Coefficient					.19*

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

significant positive correlation between Gender and University Major (Science/Non-Science). Proportionally more ISB Physics students who are males are entering science fields than females. Cultural Groups are seen to have no correlation with any of the uncontrolled variables or with the SRPP Participation variable. Unsurprisingly, there is a significant positive correlation confirmed between Science and Math Coefficient and University Major. The unexpected significant positive correlation between the Semesters of University when Surveyed and the Science and Math Coefficient is likely an artifact of the uncontrolled nature of the population, but should be noted, as it may be used later in the choice of covariate.

The final part of the exploratory investigation of this data is determination of the Pearson's correlations between the uncontrolled variables Semesters of University when Surveyed and the Science and Math Coefficient, and the TOSRA factors. The results of this calculation are shown in Table 4.6.

Studying Table 4.6, we see that only three out of eight TOSRA measures are correlated with the Semesters of University when Surveyed variable, with only weak correlations ($p < 0.10$), and one of them with a negative correlation. On the other hand, six out of the eight TOSRA measures are correlated with the Science and Math Coefficient variable, with four of those strongly correlated ($p < 0.01$). This is not surprising, as this variable is meant to be a measure of students' affinity towards and abilities in science and math, and seeing its strong correlations with the factors measured in TOSRA would be expected.

In considering the appropriateness of including a covariate in the multivariate analysis of variance, several factors must be considered. First, an appropriate covariate is unequally distributed between the groups of the independent variable (SRPP Participation status). Second, the covariate should be correlated with

Table 4.6: Correlations between selected outside variables and TOSRA factors

TOSRA Factor	Semesters of Uni When Surveyed		Science & Math Coefficient	
	Pearson Correlation	Sig.	Pearson Correlation	Sig.
Combined Score	0.07	0.203	0.33***	0.000
Factor S: Social Implications of Science	0.15**	0.041	0.07	0.209
Factor N: Normality of Scientists	0.13*	0.069	0.22**	0.004
Factor I: Attitude to Scientific Inquiry	0.05	0.263	0.07	0.200
Factor A: Adoption of Scientific Attitudes	0.08	0.159	0.16**	0.029
Factor E: Enjoyment of Science Lessons	0.09	0.152	0.32***	0.000
Factor L: Leisure Interest in Science	0.02	0.400	0.32***	0.000
Factor C: Career Interest in Science	-0.11*	0.099	.025***	0.001

* Correlation is significant at the 0.10 level (1-tailed).
** Correlation is significant at the 0.05 level (1-tailed).
*** Correlation is significant at the 0.01 level (1-tailed).

the dependent variables. Third, the covariate must be a scale variable (Stevens, 2009, p. 207). Looking at this situation, it can be seen that the Semesters of University when Surveyed variable fulfills the first criterion, but only weakly fulfills the second criterion, with only three out of eight factors correlated. The third criterion is also an issue for this variable. The Semesters of University when Surveyed variable has values of 0, 3, 5, and 7. While technically a scale variable, its spread of values is limited, and thus its effectiveness as a covariate is also limited.

Looking at the Science and Math Coefficient variable, we see that while it is relatively equally distributed between the two groups, it is correlated with six out of eight TOSRA factors, and, importantly, it is a true scale variable with continuous values ranging from 1.7 up to 25.8. The additional consideration that the Science and Math Coefficient variable is correlated to the Semesters of University when Surveyed variable at the $p < 0.05$ level (Table 4.5) led to the decision that a covariate was appropriate, and the appropriate covariate to use was the Science and Math Coefficient variable. It was thus decided that a multivariate analysis of covariance (MANCOVA), with the Science and Math Coefficient variable as the covariate, would be used to analyze the data.

Testing for Satisfaction of Assumptions for MANCOVA

Before a MANCOVA was run to determine the effect of the SRPP on the seven TOSRA factors and the combined TOSRA score, tests were performed to see if all necessary assumptions (normality, linearity, homogeneity of variance and covariance, and homogeneity of interaction effects) (Stevens, 2009, p 218) were met. The Shapiro-Wilk's test, shown in Table 4.7, was performed to test for the normality of the data.

It is clear that much of the data does not satisfy the assumption for normality. At least one of the groups in seven out of eight factors violates normality, and six of these show serious violation ($p < 0.01$). While MANCOVA is robust to violations of normality (Stevens, 2009, p 223), the results of the Shapiro-Wilk's tests put the reliability of any results of the MANCOVA statistic in doubt. It is suggested that the use of a non-parametric statistic would be more appropriate.

In spite of the Shapiro-Wilk results, it was decided to conduct the rest of the tests for the violations of assumptions, in the interest of thoroughness. The results are presented in Table 4.8.

Table 4.7: The Shapiro-Wilk's test for normality was performed on the data.

TOSRA Factor	Student SRPP Status	Shapiro-Wilk (Sig.)
Combined Score	Not in SRPP	0.576
	In SRPP	0.006*
Factor S: Social Implications of Science	Not in SRPP	0.253
	In SRPP	0.000*
Factor N: Normality of Scientists	Not in SRPP	0.080
	In SRPP	0.081
Factor I: Attitude to Scientific Inquiry	Not in SRPP	0.184
	In SRPP	0.001*
Factor A: Adoption of Scientific Attitudes	Not in SRPP	0.016*
	In SRPP	0.001*
Factor E: Enjoyment of Science Lessons	Not in SRPP	0.203
	In SRPP	0.000*
Factor L: Leisure Interest in Science	Not in SRPP	0.659
	In SRPP	0.006*
Factor C: Career Interest in Science	Not in SRPP	0.907
	In SRPP	0.044*
* $p < 0.05$ indicates violation of normality		

The assumption of linearity between the covariate and the dependent variables was tested and shown to be satisfied for all factors except factors S and I. This suggests that the covariate Science and Math Focus has negligible effect on Factors S and I, meaning that the MANOVA and MANCOVA statistics will give the same results for these factors. This was confirmed to be correct by performing a MANOVA on the data.

The next assumption to be tested was for homogeneity of variance, using Levene's test. This assumption was not violated for any factors, indicating that homogeneity of variance requirement for applying MANCOVA was satisfied. Finally, the homogeneity of regression slopes assumption was tested by looking at the significance of interaction effects between the independent variable and the proposed

Table 4.8: Tests for Violations of MANCOVA Assumptions.

TOSRA Factor	Test for Linearity[a] (Sig.)	Levene's Test[b] (Sig.)	Interaction Effect[c] (Sig.)
Combined Score	0.000*	0.483	0.021*
Factor S: Social Implications of Science	0.400	0.675	0.128
Factor N: Normality of Scientists	0.009*	0.373	0.017*
Factor I: Attitude to Scientific Inquiry	0.359	0.384	0.322
Factor A: Adoption of Scientific Attitudes	0.036*	0.372	0.251
Factor E: Enjoyment of Science Lessons	0.000**	0.775	0.745
Factor L: Leisure Interest in Science	0.000**	0.337	0.080
Factor C: Career Interest in Science	0.003**	0.369	0.043*

a Covariate has an effect for $p < 0.05$.
b Homogeneity of variance assumption voilated for $p < 0.05$.
c Homogeneity of regression slopes assumption violated for $p < 0.05$.
* Significant to the $p < 0.05$ level.
** Significant to the $p < 0.01$ level.

covariate. As seen in final column of Table 4.8, this assumption was violated for three of the eight measures.

Testing for Differences of Means

Given the serious issues with satisfying several of the requirements of applying the MANCOVA statistic, it was decided that simple non-parametric comparison of means tests would yield results with higher confidence levels. Two commonly used non-parametric tests are the Mann-Whitney U test, and the t-test with equality of variance *not* assumed (Stevens, 2009). In the interest of completeness and thoroughness, and to increase confidence in the conclusions, both the MANCOVA and the non-parametric tests were performed and their results compared.

The MANCOVA was run with the Bonferroni adjustment for multiple comparisons (Johnson, 1998, p 442) to determine the effect of the SRPP on the factors tested by the TOSRA instrument, after controlling for the variable Science and Math Coefficient. The results of the MANCOVA are shown in Table 4.9, and those of the Mann-Whitney U and t-test are shown in Table 4.10, on the following pages.

Table 4.9: MANCOVA results for TOSRA, showing significance of differences of means, along with effect size, for students in SRPP compared to those not in SRPP, controlling for Science and Math Coefficient.

TOSRA Factor	Tests of Between-Subjects Effects		Effect Size ('In SRPP' - 'Not in SRPP')
	F	Sig.	
Combined Score	0.85	0.36	-
Factor S: Social Implications of Science	2.33	0.13	-
Factor N: Normality of Scientists	0.50	0.48	-
Factor I: Attitude to Scientific Inquiry	0.52	0.47	-
Factor A: Adoption of Scientific Attitudes	0.01	0.94	-
Factor E: Enjoyment of Science Lessons	4.68	0.03*	+0.25
Factor L: Leisure Interest in Science	0.10	0.75	-
Factor C: Career Interest in Science	0.02	0.90	-
* significant to the $p < 0.05$ level			

It is clear from Tables 4.10 and 4.11 that both the Mann-Whitney U and the t-test show similar results and are supported by the MANCOVA results. Conclusions can be drawn with reasonable levels of confidence.

Table 4.10: Non-parametric Mann-Whitney and t-test results.

TOSRA Factor	Mann-Whitney U (Asymptotic Sig.)	Independent Samples t-tests Equal variances not assumed (Sig.)
Combined Score	0.107	0.194
Factor S: Social Implications of Science	0.057	0.108
Factor N: Normality of Scientists	0.499	0.699
Factor I: Attitude to Scientific Inquiry	0.406	0.456
Factor A: Adoption of Scientific Attitudes	0.882	0.907
Factor E: Enjoyment of Science Lessons	0.006**	0.022*
Factor L: Leisure Interest in Science	0.271	0.438
Factor C: Career Interest in Science	0.565	0.627

* Significant to the $p < 0.05$ level.
** Significant to the $p < 0.01$ level.

Results

Objective 1. To determine the effect of the SRPP on students' science-related attitudes.

The results show no significant differences between students in the SRPP and students who were not in the SRPP for all factors measured by TOSRA *except* for **Factor E: Enjoyment of Science Lessons**.

The lack of difference on most of the factors is not surprising, when the nature of the SRPP at ISB is considered. Students in both the Treatment Group and the Control Group experienced the standard inquiry-based science courses including IRP's in grades 9 and 10. In grades 11 and 12, both groups experienced the prescribed IB Physics course, with the same content and experimental design and reporting standards.

The SRPP only introduces a difference in the nature and the level of the independent inquiry done in the IB course, along with offering students the possibility to publish their results. The SRPP creates no differences in the nature or number of 'learning' labs done in the IB course to teach concepts, nor does it change the curriculum, the theoretical course content. These aspects of a course, along with students' natural affinities and abilities and their grade 9 and 10 experience in science courses, would be expected to have important effects on the attitudes measured in TOSRA. Hence, it is not particularly surprising that the presence or absence of the SRPP in students' last two years of high school, is not correlated to significant differences in most of these attitudes.

Looking at the one factor that is correlated to participation in the SRPP, Enjoyment of Science Lessons, it would be convenient to assume that the SRPP was the *cause* of this difference. However, more careful consideration leads us to be wary of that conclusion. The Enjoyment of Science Lessons is likely to be a sum of students' enjoyment of all activities in a science class: lectures, homework, demonstrations, activities, group work, presentations, learning labs, and Independent Research, to name a few. The SRPP can be expected to have a significant direct effect on only one of these, Independent Research, so it not unreasonable to question whether this measured difference is caused by the SRPP, or is merely correlated to it. It must be noted that only three teachers taught all the students in the study, with one teacher, the author, teaching all the SRPP students, and two other teachers teaching all the non-SRPP students. Given that teacher philosophy, personality, behaviors, attitudes, and style in running the lessons and the course is expected to have an important impact on student enjoyment, one suspects that the SRPP might not be the most important factor in causing the difference in levels of enjoyment of science lessons detected here. It is therefore suggested that, while the results do show a significant difference in this factor, a reasonable level of confidence in the conclusion that the SRPP is the *cause* of this difference is not justified.

Data Analysis

Objective 2: To determine the effect of the SRPP on students' understanding of the Nature of Science.

To review, the purpose of the data analysis for Objective 2 is to determine the effects of the SRPP on students' understanding of the Nature of Science, as measured by the Student Understanding of Science and Scientific Inquiry (SUSSI) survey instrument. The Independent Variable is 'Participation in the SRPP', with the Treatment Group enrolled in an IB Physics course with the SRPP integrated into the course, and the Control Group enrolled in an IB Physics course with no SRPP. The

Dependent Variable for Objective 2 is students' understanding of NOS, as measured by the SUSSI survey instrument. The method of the data analysis used to accomplish the purpose is to compare the means of the results of the two groups in the study using a multivariate analysis of covariance, with the previously defined Science and Math Coefficient as the covariate. The expected result of the data analysis is a determination of whether there is a significant difference in student understanding of the nature of science between the two groups being studied.

The SUSSI has been well tested for reliability and validity, as previously described, and no changes were made to the instrument for this study, so no reliability or validity testing was done here.

Descriptive Statistics

The results of the SUSSI Likert-type responses for students who were in the SRPP are presented in Table 4.11. Each of the four items in each factor in this instrument was rated on a scale from "Strongly Agree" (5) to "Strongly Disagree" (1), as with the TOSRA items. A mean factor score of above 3.5 was defined to indicate an "informed view" of that aspect of NOS, with 4.0 or above considered "well-informed". A score between 2.51 and 3.50 indicated a "transitional view" of that aspect, and a score below 2.50 indicated a "naïve view" of that aspect of NOS.

The results show that SRPP students have informed views of four out of the six NOS aspects, with transitional views for two. **Factor 1. Observations and Inferences** shows a mean of 3.80, indicating informed views towards this aspect of NOS, with 69% of students scoring 4 or above. **Factor 2. Change of Scientific Theories** was the NOS aspect with the highest results, with a mean of 4.21, well within the informed range, with 78% of students holding informed views. Students showed the weakest understanding of **Factor 3. Scientific Laws vs. Theories** with a

Table 4.11: SUSSI results for students who participated in the SRPP

SUSSI Factor	N	Mean	SD	Interpre-tation	Percent Responses >= 4
Combined Score	110	3.61	0.41	Informed View	18
Factor 1. Observations and Inferences	110	3.80	0.67	Informed View	54
Factor 2. Change of Scientific Theories	110	4.21	0.52	Well-Informed View	78
Factor 3. Scientific Laws vs. Theories	110	2.99	0.57	Transitional View	6
Factor 4. Social and Cultural Influence on Science	110	3.64	0.76	Informed View	42
Factor 5. Imagination and Creativity in Scientific Investigations	110	3.31	0.92	Transitional View	31
Factor 6. Methodology of Scientific Investigation	110	3.69	0.54	Informed View	41

mean of 2.99 and only 6% of students holding informed views. The average SRPP student held transitional views of this aspect, with many showing naïve views. **Factor 4. Social and Cultural Influence on Science** returned a mean of 3.64 with 42% of students holding well-informed views. For the final two factors, **Factor 5. Imagination and Creativity in Scientific Investigations** showed that the average student holds a transitional view of this aspect, with a mean of 3.31, and the proportion of students holding well-informed views of this aspect at 31%, while **Factor 6. Methodology of Scientific Investigation** had a mean of 3.69, indicating an informed view for students, with the proportion of students holding well-informed views in this aspect at 41%.

As with the previous results, while interesting, without a context these results mean little. Therefore, the results of this study were placed in a wider context of research results by comparing to results from three other studies. The first study (Liang et al, 2008) was carried out on 640 university students studying to become teachers. The second (Clough et al, 2010) administered SUSSI to 134 university students in the US taking an introductory Biology course, while the third (Saderholm, 2007) reported SUSSI results for 50 experienced science teachers in the state of Kentucky in the US. While studies reporting SUSSI results for secondary school students were searched for, none with appropriate characteristics were found.

It was found that SRPP students showed similar understandings, within standard deviations, on all of the factors, as compared to the groups in these three studies, in spite of their differences in age, educational-level, and country. Interestingly, the comparison groups show the same pattern as the SRPP students, showing the least informed views of Factor 3. Scientific Laws vs Theories, and showing the most informed views of Factor 2. Change in Scientific Theories. It is also interesting to note that the NOS Understanding of the SRPP students was at about the same level as university introductory biology students, pre-service teachers, and experienced science teachers, even though SRPP students were younger, had studied science less, and were less experienced in general. As previously stated, while it is difficult to know the reasons for this, it is suggested that this may be due to the fact that the SRPP students have all elected to enroll in IB Physics, indicating an affinity and talent for science and math, which could be expected to result in higher understanding of NOS. Again, while no statistical tests for significant differences can be done between these groups, it is helpful to compare these results as a way of placing the results of the current study within the context of other research in the field.

Having reported the results of the SUSSI instrument for SRPP participants, and placed them in the context of other research, it is now time to address the relevant research question: How does the SRPP affect students' understanding of the Nature of Science, as measured by this instrument. This will be done by comparing the SUSSI results of SRPP participants in the IB Physics program at ISB with students in IB Physics classes at ISB that did not participate in the SRPP. Descriptive statistics comparing responses of these two groups are shown in Table 4.12, on the following page.

While the number of respondents not in the SRPP (N = 29) was much lower than the number that were in the SRPP (N = 110), due to the characteristics and limitations of the available populations, it is quickly obvious that there is little

Table 4.12: SUSSI results from the Control and Treatment Groups, students **not** participating in the SRPP and students participating in the SRPP in IB Physics at ISB.

SUSSI Factor	Student SRPP Status	N	Mean	SD	Percent Responses >= 4
Combined Score	Not in SRPP	29	3.65	0.34	10
	In SRPP	110	3.61	0.41	18
Factor 1. Observations and Inferences	Not in SRPP	29	3.96	0.45	59
	In SRPP	110	3.80	0.67	54
Factor 2. Change of Scientific Theories	Not in SRPP	29	4.28	0.44	86
	In SRPP	110	4.21	0.52	78
Factor 3. Scientific Laws vs. Theories	Not in SRPP	29	2.88	0.62	3
	In SRPP	110	2.99	0.57	6
Factor 4. Social and Cultural Influence on Science	Not in SRPP	29	3.67	0.75	55
	In SRPP	110	3.64	0.76	42
Factor 5. Imagination and Creativity in Scientific Investigations	Not in SRPP	29	3.27	0.79	28
	In SRPP	110	3.31	0.92	31
Factor 6. Methodology of Scientific Investigation	Not in SRPP	29	3.83	0.62	52
	In SRPP	110	3.69	0.54	41

difference between the two groups in all areas. All six SUSSI factors, as well as the combined SUSSI score, show the mean response of students in the SRPP to be little different from those not in the SRP. This pattern is repeated when looking at the proportion of respondents who answered positively for each factor. While it is unlikely that there is a significant difference between any of these means, unless the possibility of an important difference between the groups or the presence of a strong covariate can be eliminated, we cannot be sure of this.

Testing for Covariates

As described in the previous section, tests were done to determine if there were any uncontrolled, outside variables that might have an impact on the results that show significant difference between the groups. The results of these tests were shown in Tables 4.5 and 4.6. Table 4.5 showed that the only variable showing a significant difference in means between the populations of the two groups was the Semesters of University Completed when Surveyed, while Table 4.6 showed a positive correlation between Semesters of University when Surveyed and Science and Math Coefficient.

Continuing the exploratory investigation into the SUSSI results, the correlations between these two uncontrolled variables and the dependent variables, the SUSSI factors, were investigated. This was done in order to better understand any other influences affecting the results and to determine which of these factors it might be necessary to use as a covariate in the MANCOVA of the differences in means between groups. The resulting Pearson's correlation calculations are shown in Table 4.13.

Table 4.13: Correlations between selected outside variables and SUSSI factors

SUSSI Factor	Semesters of Uni When Surveyed		Science & Math Coefficient	
	Pearson Correlation	Sig.	Pearson Correlation	Sig.
Combined Score	0.06	0.230	0.37***	0.000
Factor 1. Observations and Inferences	-0.09	0.144	0.17**	0.024
Factor 2. Change of Scientific Theories	0.14**	0.047	0.25***	0.002
Factor 3. Scientific Laws vs. Theories	-0.01	0.452	0.21***	0.008
Factor 4. Social and Cultural Influence on Science	0.08	0.189	0.29***	0.000
Factor 5. Imagination and Creativity in Scientific Investigations	0.11*	0.096	0.24***	0.002
Factor 6. Methodology of Scientific Investigation	-0.02	0.396	0.19**	0.013

* Correlation is significant at the 0.10 level (1-tailed).
** Correlation is significant at the 0.05 level (1-tailed).
*** Correlation is significant at the 0.01 level (1-tailed).

Studying Table 4.13, we see that all SUSSI factors are strongly correlated with the Science and Math Coefficient variable ($p \leq 0.01$ for all but one with $p < 0.05$). On the other hand, only two of the SUSSI measures are correlated with the Semesters of University when Surveyed variable, with one only at the $p < 0.10$ level. It seems that age and experience at university have little effect on ISB students understanding of NOS.

Looking at the Science and Math Coefficient variable, we see that while it is relatively equally distributed between the two groups, it is correlated with every one of the factors, and, importantly, it is a true scale variable. The additional consideration that the Science and Math Coefficient variable is correlated to the Semesters of University when Surveyed variable at the $p < 0.05$ level (Table 4.6) led to the decision that a covariate is appropriate, and the appropriate covariate to use is the Science and Math Coefficient variable. It was thus decided that a multivariate analysis of covariance (MANCOVA) with the Science and Math Coefficient variable would be used to analyze the data.

Testing for Satisfaction of Assumptions for MANCOVA

Before a MANCOVA is run to determine the effect of the SRPP on the six SUSSI factors and the combined SUSSI score, tests were performed to see if all necessary assumptions (normality, linearity, homogeneity of variance and covariance, and homogeneity of interaction effects) (Stevens, 2009, p 218) were met. The Shapiro-Wilk's test, shown in Table 4.14, was performed to test for the normality of the data.

Table 4.14: The Shapiro- Wilk's test for normality was performed on the SUSSI data.

SUSSI Factor	Student SRPP Status	Shapiro-Wilk (Sig.)
Combined Score	Not in SRPP	0.040*
	In SRPP	0.874
Factor 1. Observations and Inferences	Not in SRPP	0.071
	In SRPP	0.001*
Factor 2. Change of Scientific Theories	Not in SRPP	0.002*
	In SRPP	0.000*
Factor 3. Scientific Laws vs. Theories	Not in SRPP	0.615
	In SRPP	0.004*
Factor 4. Social and Cultural Influence on Science	Not in SRPP	0.000*
	In SRPP	0.000*
Factor 5. Imagination and Creativity in Scientific Investigations	Not in SRPP	0.077
	In SRPP	0.000*
Factor 6. Methodology of Scientific Investigation	Not in SRPP	0.474
	In SRPP	0.011*

* $p < 0.05$ indicates violation of normality

It is clear that much of the data does not satisfy the assumption of normality, with at least one of the groups in every factor violating normality, with five of those showing serious violation (p < 0.01). While MANCOVA is robust to violations of normality (Stevens, 2009, p 223), the results of the Shapiro-Wilk tests put the reliability of any results of the MANCOVA statistic in doubt. It is suggested that the use of a non-parametric statistic would be more appropriate.

As with the TOSRA analysis, in spite of the Shapiro-Wilk results, it was decided to conduct the rest of the tests for the violations of assumptions, in the interest of thoroughness. The results are presented in Table 4.15 below.

Table 4.15: Tests for Violations of MANCOVA Assumptions of the SUSSI results.

SUSSI Factor	Test for Linearity[a] (Sig.)	Levene's Test[b] (Sig.)	Interaction Effect[c] (Sig.)
Combined Score	0.041*	0.842	0.109
Factor 1. Observations and Inferences	0.004**	0.045*	0.033*
Factor 2. Change of Scientific Theories	0.030*	0.962	0.070
Factor 3. Scientific Laws vs. Theories	0.002**	0.294	0.977
Factor 4. Social and Cultural Influence on Science	0.009**	0.696	0.562
Factor 5. Imagination and Creativity in Scientific Investigations	0.022*	0.811	0.271
Factor 6. Methodology of Scientific Investigation	0.022*	0.258	0.900

a Covariate has an effect for p < 0.05.
b Homogeneity of variance assumption voilated for p < 0.05.
c Homogeneity of regression slopes assumption violated for p < 0.05.
* Significant to the p < 0.05 level.
** Significant to the p < 0.01 level.

The assumption of linearity between the covariate and the dependent variables was tested and shown to be satisfied for all factors (Table 4.15). The next assumption to be tested was for homogeneity of variance, using Levene's test. This assumption was only violated for Factor 1 (and only just, with $p = 0.045$), indicating that homogeneity of variance requirement for applying MANCOVA was satisfied for all but that factor. Finally, the homogeneity of regression slopes assumption was tested by looking at the significance of interaction effects between the independent variable and the proposed covariate. As seen in the final column of Table 4.15 above, this assumption was violated for only Factor 1, again indicating that the MANCOVA results will be reliable for all but that factor.

Testing for Differences of Means

Given that Factor 1 had issues with satisfying several of the requirements of applying the MANCOVA statistic, it was decided the Mann-Whitney U test, and the t-test with equality of variance *not* assumed would be run on this factor. Both the Mann-Whitney test and the t-test confirmed the results of the MANCOVA for these factors, are shown in Table 4.16.

Table 4.16: Mann-Whitney and t-test performed for SUSSI Factor 1 to verify that the MANCOVA results are reliable in spite of the violation of the homogeneity of variance.

SUSSI Factor	**Mann-Whitney U (Asymptotic Sig.)**	**Independent Samples t-tests Equal variances not assumed (Sig.)**
Factor 1. Observations and Inferences	0.367	0.141
* Significant to the $p < 0.05$ level.		

The MANCOVA was run with the Bonferroni adjustment for multiple comparisons (Johnson, 1998, p 442) to determine the effect of the SRPP on the factors tested by the TOSRA instrument, after controlling for the covariate Science and Math Coefficient. The results of the MANCOVA are shown in Table 4.17, on the following page.

Table 4.17: MANCOVA results for SUSSI, showing significance of differences of means, along with effect size, for students in SRPP compared to those not in SRPP, controlling for Science and Math Coefficient.

SUSSI Factor	Tests of Between-Subjects Effects		Effect Size ('In SRPP' - 'Not in SRPP')
	F	Sig.	
Combined Score	0.83	0.37	-
Factor 1. Observations and Inferences	1.84	0.18	-
Factor 2. Change of Scientific Theories	0.98	0.32	-
Factor 3. Scientific Laws vs. Theories	0.54	0.46	-
Factor 4. Social and Cultural Influence on Science	0.20	0.66	-
Factor 5. Imagination and Creativity in Scientific Investigations	0.00	0.98	-
Factor 6. Methodology of Scientific Investigation	1.99	0.16	-

Results

Objective 2. To determine the effect of the SRPP on students' understanding of the Nature of Science.

It is clear, from Tables 4.16 and 4.17, that the MANCOVA results (supported by the Mann-Whitney U and t-test results for Factor 1), lead us to conclude that there are no significant differences between students in the SRPP and students who were not in the SRPP for *all* factors measured by SUSSI. As discussed previously for the TOSRA results, the lack of difference in understanding of NOS is not surprising, when the nature of the SRPP is considered. The SRPP creates little difference in the nature or number of 'learning' labs done in the course to teach concepts, nor does it change the curriculum, the theoretical course content. These aspects of a course, along with students' natural affinities and abilities and their historical experience in science, would be expected to have important effects on NOS understanding. It has also been noted that research has shown that improving students' understanding of NOS requires direct instruction on the topic (Abd-El-Khalick, 2001), which does not occur as a part of the SRPP. Hence, it is not surprising that the presence or absence of the SRPP in students' last two years of high school is not correlated to differences in the understanding of NOS.

Results from SUSSI Open-ended responses

In order to triangulate with the Likert-type questions in the SUSSI, as well as to increase the richness of our understanding of the respondents' views, an open-ended question is included at the end of each section, asking each student to describe their understanding of that aspect of NOS (Liang et. al., 2006). The rubric for scoring the open-ended responses, developed by Liang et al (2009) and modified by Miller et al (2010) and shown in Appendix C.3, was used to analyze the responses. Responses are rated as demonstrating an 'informed view', 'transitional view', or 'naïve view' of each aspect of NOS as defined and measured by the instrument. The results are presented in Table 4.18.

It may first be noted that the numbers of responses is less than the numbers for the previous SUSSI data, as many respondents failed to respond to the open-ended questions, or gave responses that could not be rated. Secondly, it can be seen that the understanding of the aspects of NOS demonstrated by the open-ended responses broadly parallels that of the quantitative analysis done previously. To confirm this observation, the Pearson correlation between the quantitative and open-ended response results for each factor were calculated, and presented in Table 4.19.

As can be seen from Table 4.19, there is indeed a strong correlation between the quantitative and qualitative responses to each NOS factor, as would be

Table 4.18: The rated results of the open-ended responses from SUSSI.

Open-ended Response Rating: SUSSI Factor	N	Percent Respondents Holding View		
		Informed	Transitional	Naïve
Factor 1. Observations and Inferences	92	41	55	3
Factor 2. Change of Scientific Theories	81	20	80	0
Factor 3. Scientific Laws vs. Theories	70	11	10	79
Factor 4. Social and Cultural Influence on Science	75	19	77	4
Factor 5. Imagination and Creativity in Scientific Investigations	74	27	68	5
Factor 6. Methodology of Scientific Investigation	43	23	51	26

Table 4.19: The Pearson Correlation between the SUSSI Factor Score from 4 Likert Items and the Scored Open-ended Response for that Factor.

SUSSI Factor	Pearson Correlation
Factor 1. Observations and Inferences	0.464**
Factor 2. Change of Scientific Theories	0.253*
Factor 3. Scientific Laws vs. Theories	0.265*
Factor 4. Social and Cultural Influence on Science	0.397**
Factor 5. Imagination and Creativity in Scientific Investigations	0.469**
Factor 6. Methodology of Scientific Investigation	0.464**
* Significant at the $p < 0.05$ level. ** Significant at the $p < 0.01$ level.	

expected. Given this, it was decided that performing a MANCOVA comparing the responses of students in the SRPP to students not in the program, as has been done previously, would add no new understanding, and thus would not be performed.

However, it would be valuable, in the interest of enriching our understanding of students' knowledge of NOS, to look more closely at the results presented in Table 4.18. **Factor 1, Observations and Inferences** shows an almost even split between informed and transitional views, with almost no naïve views. Some students seem to have a deep understanding of this aspect of NOS, with a typical response being:

> "Not all scientists observe the same things in the same ways, shifts in focus and the expectation of the research may skew the observational skills towards the expectations of the researcher, hence changing the outcome of the observations, making them a variable of the researcher and not a common factor to the lab."

This is very well put, showing a profound awareness of the role of the human researcher in determining the outcomes of experiments.

The second factor, **Change of Scientific Theories**, while having no naïve responses, showed few students with truly informed views of this aspect of NOS, according to the scoring rubric. The rubric requires that students state not only that theories change over time as new evidence if found, but also to add that existing evidence, re-interpreted, also leads to changes in theory. It is suspected that a portion of students rated as transitional do understand the possibility of re-interpreting existing evidence, but neglected to include that in their responses.

The third factor, **Scientific Laws vs Theories**, showed mostly naïve views among the students, not unlike results presented from other studies in Table 4.13. Typical responses included: "it seems that scientific laws have a higher level of confidence than scientific theories", "Theories can be hypothetic, while laws are rules that have been proved", and "Scientific laws have been proven with an almost 100% certainty while theories may still be disputed." While some might be surprised, it must be admitted that before beginning research into NOS, the author held naïve views of the difference between scientific laws and theories. Further, the author informally polled a number of teacher colleagues, and found naïve views common among them as well. So it is not surprising that so many students hold naïve views, since their teachers do also.

The fourth factor, **Social and Cultural Influence on Science**, showed no naïve views, but few informed views. Again, it is suspected that this lack of informed views may not be truly reflective of student understanding, but more due to the rubric requiring that students state that both what AND how science is done is influenced. While most students discussed one or the other, then stopped, few took the time to point out both aspects of influence.

The fifth factor, **Imagination and Creativity in Scientific Investigations**, showed almost no students with naïve views, many with transitional views, and a relatively small proportion with informed views. Most students with transitional views implied that creativity and imagination could not be employed when objectivity was needed in observing and analyzing data, failing to understand that these can exist together.

The final factor, **Methodology of Scientific Investigation**, showed roughly a quarter of the students with naïve views, and a quarter with informed views, with the remaining half of the students holding transitional views. Statements such as, "The scientific method is a universal method in conducting scientific investigations," were typical of the naïve view. Looking at the open-ended responses to the NOS factors has been useful, as they have confirmed and enriched the findings from the quantitative results.

At this point in our analysis of the results, it would be understandable for the reader to begin to question the value of the SRPP. After having looked at two of the four instruments used in the study, the SRPP has not demonstrated any effect on student outcomes. However, it is important to keep in mind that one of the guiding considerations of this study was understanding that, when studying something as complex as an educational program, with its myriad participants and factors at play, it is important to build as rich and comprehensive a picture of the situation as possible. It was also felt that, with the history in education of new programs touted as cure-alls, the study should look at a wide range of effects, so that limitations of the program, what the SRPP does *not* affect, are also clearly shown.

It is now time to turn to the third objective of this study.

Data Analysis

Objective 3: To determine the effect of the SRPP on students' experimental research and publishing skills and attitudes.

Having looked at the effects of the SRPP on student science-related attitudes and on student understanding of the Nature of Science, it is time to look at the effects of the program on students' abilities in and attitudes toward experimental research and publishing.

To review, the purpose of the data analysis for Objective 3 is to determine the effects of the SRPP on students' experimental research and publishing skills and attitudes. The Independent Variable is 'Participation in the SRPP', with the Treatment Group enrolled in an IB Physics course with the SRPP integrated into the course, and the Control Group enrolled in an IB Physics course with no SRPP. The Dependent Variable for Objective 3 is students' experimental research and publishing skills and attitudes, as measured by the two survey instruments, the Secondary Science Research Student Self-Assessment (SSRSSA) and the Attitudes toward and Effects of Student Publishing (AESP), which will be used to address this objective.

The methods of the data analysis used to accomplish the purpose is, for the SSRSSA Likert-type items, to compare the means of the results of the two groups in the study using a multivariate analysis of covariance, with the previously defined Science and Math Coefficient as the covariate. For the AESP Likert-type item results, descriptive statistics of the results of the Treatment Group will be used to interpret the findings. Finally, for the open-ended responses of the two instruments, inductive thematic analysis will be used to triangulate the quantitative results and enrich understanding of the effects of the SRPP on student research and publishing skills and attitudes.

The expected result of the data analysis is a determination of whether there is a significant difference in student research and publishing skills and attitudes between the two groups being studied, and to enrich the descriptions and understandings of the differences with the qualitative results.

Reliability of the SSRSSA Instrument

The first tool used was the Secondary Science Research Student Self-Assessment (SSRSSA). As described previously, SSRSSA is a version of the Undergraduate Research Student Self-Assessment (URSSA) (Hunter et al, 2009) survey modified to be appropriate for use with secondary school students. The SSRSSA consisted of eight sections. The first five sections formed the core sections of the instrument. The items in each of these first five sections were aggregated to form five factors related to research skills and attitudes. The items in the last three sections were not grouped and defined as factors, thus the items were analyzed individually.

All items of the five core sections of the URSSA remained substantively unchanged in the SSRSSA, with only modified wording to indicate the different context in which the student research was conducted. The five factors represented by the first five sections of the SSRSSA were tested for reliability using Cronbach's alpha with the results shown in Table 4.20. As can be seen, each factor of the instrument, as well as the instrument as a whole, demonstrated high levels of reliability with alphas ranging from 0.72 to 0.93. These values were in line with values reported for the URSSA instrument (Thiry, Weston, Laursen, and Hunter, 2012), indicating that the context-based wording changes did not affect the reliability of the instrument.

Table 4.20: The results of the reliability test for the five core factors of the SSRSSA instrument, as well as the combined results for the instrument as a whole.

SSRSSA Factor	N	N of Items	Cronbach's alpha
Factor 1. Thinking and Working Like a Scientist	65	8	0.766
Factor 2. Personal Gains	65	8	0.729
Factor 3. Gains in Skills	65	13	0.723
Factor 4. Attitudes and Behaviors	65	8	0.846
Factor 5. Experience in Science Class[a]	65	6	0.774
Instrument as a Whole	65	43	0.931

Descriptive Statistics: SSRSSA

The results of the Likert-type responses for the first five sections, representing the five factors of the SSRSSA for students who were in the SRPP, are presented in Table 4.21.

Table 4.21: SSRSSA results for students who participated in the SRPP

SSRSSA Factor	N	Mean	SD	Interpre-tation	Percent Responses >= 4
Combined Score	109	3.68	0.43	Good Gain	24
Factor 1. Thinking and Working Like a Scientist	109	4.23	0.47	Good Gain	73
Factor 2. Personal Gains	109	3.99	0.52	Good Gain	56
Factor 3. Gains in Skills	109	3.68	0.53	Good Gain	34
Factor 4. Attitudes and Behaviors	109	3.41	0.69	Moderate Gain	24
Factor 5. Experience in Science Class[a]	109	3.28	0.47	Good Gain	77[b]

a Scale for factor 5 was 1-4
b Percent responses >= 3.

Factor 1. Thinking and working like a scientist: Application of knowledge to experimental research work shows a mean of 4.23, meaning students had "Good Gain," with 73% of students responding "Good" or "Great Gain." **Factor 2. Personal gains related to experimental research work** shows a mean of 3.99, a student assessment of "Good Gain", but just 0.01 points below a rating of "Great Gain", with 56% of students reporting "Good" or "Great" gains. **Factor 3. Gains in skills related to experimental research work** is slightly lower, but with the average student still reporting "Good Gain" in skills, and with only 34% reporting "Good" or "Great" gains, while **Factor 4. Attitudes and behaviors related to experimental research work** corresponds to a rating between "Some" and "A fair amount" on the attitudes and behaviors queried, with only 24% rating this factor either "A fair amount" or "A great deal." Finally **Factor 5. Your experience in your science class this year** was on a four-point Likert scale, with 3.28 interpreted as "Good", and 77% of students rating this factor as "Good" or "Excellent".

Again, while interesting, without a context these results mean little. One of the reasons that existing instruments were chosen for use in this study was to allow the results of this study to be placed in a wider context of research results from other studies. The results of the core factors of SSRSSA for SRPP students in this study was compared with the results of the core factors of the related URSSA instrument administered to three groups of undergraduate research students by Weston (2012b). Weston presents the results for the first four factors in the URSSA instrument for students in summer Research Experiences for Undergraduates programs in Biology (BIO-REU) for 2010 and 2011, as well as a third group consisting of students in REU's in other sciences.

It was shown that SRPP students, while only in secondary school, showed similar benefits and effects, within uncertainty, as compared to undergraduates working in labs during summer programs. The only factor that seems different is Factor 4, with SRPP secondary school students being noticeably lower than the undergraduate students. This is not surprising as the undergraduates were participating in cutting edge research in university and corporate labs, increasing their feeling of contributing and being part of the scientific community. Factor 5 was not reported by Weston (2012b) so no comparisons can be made. Again, while no statistical tests for significant differences can be done between these groups, it is helpful to compare these results as a way of placing the results of the current study within the context of other research in the field.

Now to turn to address the relevant research question: How does the SRPP affect students' experimental research and publishing skills and attitudes? as measured by this instrument. This will be done by comparing the SSRSSA results of SRPP participants in the IB Physics program at ISB with students in IB Physics classes that did not participate in the SRPP. Descriptive statistics comparing responses of these two groups are shown in Table 4.22.

While the number of respondents not in the SRPP (N = 29) was much lower than the number that were in the SRPP (N = 109), due to the characteristics and limitations of the available populations, it is quickly obvious that there is a difference between the two groups in all areas. All five SSRSSA core factors, as well as the combined SSRSSA score, show the mean response of students in the SRPP to be well above those not in the SRPP. This pattern is repeated when looking at the frequency of respondents who answered one of the top two choices for each factor. The differences in means range from about 0.4 for factors two and three, up to a difference of almost 0.8 for factor five. In order to understand the significance of these differences, a multivariate analysis of covariance (MANCOVA) must be performed on the data.

Table 4.22: SSRSSA results from the Control and Treatment Groups, students **not** participating in the SRPP and students participating in the SRPP in IB Physics at ISB.

SSRSSA Factor	Student SRPP Status	N	Mean	SD	Percent Responses >= 4
Combined Score	Not in SRPP	29	3.21	0.55	7
	In SRPP	109	3.68	0.43	24
Factor 1. Thinking and Working Like a Scientist	Not in SRPP	29	3.74	0.76	41
	In SRPP	109	4.23	0.47	73
Factor 2. Personal Gains	Not in SRPP	29	3.56	0.69	35
	In SRPP	109	3.99	0.52	56
Factor 3. Gains in Skills	Not in SRPP	29	3.29	0.72	21
	In SRPP	109	3.68	0.53	34
Factor 4. Attitudes and Behaviors	Not in SRPP	29	2.93	0.75	7
	In SRPP	109	3.41	0.69	24
Factor 5. Experience in Science Class[a]	Not in SRPP	29	2.50	0.57	28[b]
	In SRPP	109	3.28	0.47	77[b]

a Scale for factor 5 was 1-4
b Percent responses >= 3

Testing for Covariates: SSRSSA

As described previously, tests were done on the data to determine if there were any uncontrolled, outside variables that might have an impact on the results that show significant difference between the groups. The results of these tests were shown in Tables 4.5 and 4.6. Table 4.5 showed that the only variable showing a significant difference in means between the populations of the two groups was the Semesters of University Completed when Surveyed, while Table 4.6 showed a positive correlation between Semesters of University when Surveyed and Science and Math Coefficient.

As before, after completing these tests, the exploratory investigation into the SSRSSA results was continued by looking at the correlations between these variables and the dependent variables for this objective, the SSRSSA factors, if any. The resulting Pearson's correlation calculations are shown in Table 4.23.

Studying Table 4.23, we see that three out of the six SSRSSA measures are correlated with the Semesters of University when Surveyed variable, and four out of six SSRSSA measures are correlated with the Science and Math Coefficient variable. Following a process similar to that described in the previous sections, it was again concluded that the appropriate covariate to use is the Science and Math Coefficient variable. It was thus decided that a multivariate analysis of covariance (MANCOVA) with the Science and Math Coefficient variable as the covariate would be used to analyze the data.

Table 4.23: Correlations between selected outside variables and SSRSSA factors

SSRSSA Factor	Semesters of Uni When Surveyed		Science & Math Coefficient	
	Pearson Correlation	Sig.	Pearson Correlation	Sig.
Combined SSRSSA Score	0.14*	0.057	0.15**	0.038
Factor 1. Thinking and Working Like a Scientist	0.14*	0.056	0.15**	0.036
Factor 2. Personal Gains	0.08	0.180	0.13	0.066
Factor 3. Gains in Skills	0.07	0.220	-0.01	0.437
Factor 4. Attitudes and Behaviors	0.09	0.158	0.16**	0.030
Factor 5. Experience in Science Class	0.28***	0.000	0.16**	0.030

* Correlation is significant at the 0.10 level (1-tailed).
** Correlation is significant at the 0.05 level (1-tailed).
*** Correlation is significant at the 0.01 level (1-tailed).

Testing for Satisfaction of Assumptions for MANCOVA: SSRSSA

Before a MANCOVA was run to determine the effect of the SRPP on the five core SSRSSA factors and the combined SSRSSA score, tests were again performed to see if all necessary assumptions (normality, linearity, homogeneity of variance and covariance, and homogeneity of interaction effects) (Stevens, 2009, p 218) were met. The Shapiro-Wilk's test, shown in Table 4.24, was performed to test for the normality of the data, with all factors indicating normality except for Factors 1 and 5.

Table 4.24: The Shapiro-Wilk's test for normality was performed on the data.

SSRSSA Factor	Student SRPP Status	Shapiro-Wilk (Sig.)*
Combined Score	Not in SRPP	0.315
	In SRPP	0.174
Factor 1. Thinking and Working Like a Scientist	Not in SRPP	0.119
	In SRPP	0.010*
Factor 2. Personal Gains	Not in SRPP	0.273
	In SRPP	0.077
Factor 3. Gains in Skills	Not in SRPP	0.073
	In SRPP	0.061
Factor 4. Attitudes and Behaviors	Not in SRPP	0.321
	In SRPP	0.512
Factor 5. Experience in Science Class	Not in SRPP	0.443
	In SRPP	0.013*
* $p < 0.05$ indicates violation of normality		

Given that MANCOVA is robust to violations of normality (Stevens, 2009, p 223), the results for these factors will be accepted as valid. The other tests for the violations of assumptions were performed and the results presented in Table 4.25.

Table 4.25: Tests for Violations of MANCOVA Assumptions.

SSRSSA Factor	**Test for Linearity[a] (Sig.)**	**Levene's Test[b] (Sig.)**	**Interaction Effect[c] (Sig.)**
Combined Score	0.047*	0.016*	0.21
Factor 1. Thinking and Working Like a Scientist	0.041*	0.004**	0.37
Factor 2. Personal Gains	0.084	0.050	0.18
Factor 3. Gains in Skills	0.867	0.005**	0.33
Factor 4. Attitudes and Behaviors	0.055	0.171	0.18
Factor 5. Experience in Science Class	0.033*	0.061	0.32

a Covariate has an effect for $p < 0.05$.
b Homogeneity of variance assumption voilated for $p < 0.05$.
c Homogeneity of regression slopes assumption violated for $p < 0.01$.
* Significant to the $p < 0.05$ level.
** Significant to the $p < 0.01$ level.

The assumption of linearity between the covariate and the dependent variables was tested and shown to be satisfied for all factors except Factors 2, 3 and 4 (Table 4.25). This suggests that the covariate Science and Math Coefficient has negligible effect on Factors 2, 3, and 4, meaning that the MANOVA and MANCOVA will give the same results for these factors. This was confirmed to be correct by performing a MANOVA (results not shown) on the data.

The next assumption to be tested was for homogeneity of variance, using Levene's test. This assumption was violated for Factors 1 and 3 and for the combined SSRSSA score, indicating that the MANCOVA results may be unreliable. This issue was addressed by performing the non-parametric Mann-Whitney test and t-tests with equal variances *not* assumed for these factors.

The homogeneity of covariance was tested using Box's Test of Equality of Covariance Matrices, which showed no violation with a p-value of 0.024, satisfying the requirement that $p > 0.001$ (Lund & Lund, 2013). Finally, the homogeneity of regression slopes assumption was tested by looking at the significance of interaction effects between the independent variable and the covariate. As seen in the final column of Table 4.25 above, this assumption was satisfied for all factors.

Testing for Differences of Means: SSRSSA

As mentioned above, the failure to satisfy the assumption of homogeneity of variance for Factors 1 and 3 and the combined score indicates the need to conduct non-parametric tests comparing the means of the two groups. Both the Mann-Whitney test and the t-test were conducted, and confirmed the results of the MANCOVA for these factors, as shown in Table 4.26.

After addressing the required assumptions, the MANCOVA was run with the Bonferroni adjustment for multiple comparisons (Johnson, 1998, p 442) to determine the effect of the SRPP on the factors tested by the SSRSSA instrument, after controlling for the variable Science and Math Coefficient. The results, presented in Table 4.27, show a statistically significant difference between those students who were in the SRPP for all SSRSSA factors and the combined SSRSSA score. (Just to be thorough, a MANCOVA was also run with a covariate of Semesters of University when Surveyed, as well as running it with both covariates (results not shown)). Each of these analyses returned substantively the same results as those presented in Table 4.27.

Table 4.26: Mann-Whitney and t-test performed to verify that the MANCOVA results are reliable in spite of the violation of the homogeneity of variance.

SSRSSA Factor	Mann-Whitney U (Asymptotic Sig.)	Independent Samples t-tests: Equal variances not assumed (Sig.)
Combined Score	0.001**	0.000***
Factor 1. Thinking and Working Like a Scientist	0.001**	0.003**
Factor 3. Gains in Skills	0.011*	0.010*
* significant to the $p < 0.05$ level ** significant to the $p < 0.01$ level *** significant to the $p < 0.001$ level		

SRPP program participants reported statistically significantly greater gains in **Factor 1: Thinking and working like a scientist: Application of knowledge to experimental research work** (MANCOVA $p < 0.0005$, Mann-Whitney $p = 0.001$), **Factor 2: Personal gains related to experimental research work** (MANCOVA $p < 0.0005$), and **Factor 3: Gains in skills related to experimental research work** (MANCOVA $p = 0.001$, Mann-Whitney $p = 0.011$). SRPP participants also reported statistically significantly more positive results in **Factor 4: Attitudes and Behaviors related to experimental research work** (MANCOVA $p = 0.002$), and **Factor 5: Experience in science class** (MANCOVA $p < 0.0005$).

The effect sizes for the first four factors ranged between approximately 0.4 to 0.5, or almost half of a step on the Likert scale, corresponding to SRPP students rating their gains in each of these areas half the difference between “Good Gains” and “Great Gains” higher than those not in the SRPP. **Factor 5: Experience in science class** showed a three-quarter step effect size (on only a 4 step Likert scale),

Table 4.27: MANCOVA results for SSRSSA, showing significance of differences of means, along with effect size, for students in SRPP compared to those not in SRPP, controlling for Science and Math Coefficient.

SSRSSA Factor	**Tests of Between-Subjects Effects**		**Effect Size ('In SRPP' – 'Not in SRPP')**
	F	**Sig.**	
Combined Score	23.69	0.000***	+ 0.46
Factor 1. Thinking and Working Like a Scientist	17.22	0.000***	+ 0.47
Factor 2. Personal Gains	13.21	0.000***	+ 0.43
Factor 3. Gains in Skills	10.70	0.001***	+ 0.39
Factor 4. Attitudes and Behaviors	10.16	0.002**	+ 0.46
Factor 5. Experience in Science Class	56.11	0.000***	+ 0.76

** significant to the $p < 0.01$ level
*** significant to the $p < 0.001$ level

corresponding to three-quarters of the difference between "Good" and "Excellent". The level of confidence that can be placed in these findings is quite high, given the very small p-values and the large effect sizes.

Examining the SSRSSA Factors More Closely

In order to more fully understand the details and complexities of the effects of the SRPP on students, and given that all the five core factors of the SSRSSA instrument showed a very significant difference between those in the SRPP and those not, the instrument items making up each of the SSRSSA factors will now be examined individually.

Table 4.28 presents the means for the items comprising **Factor 1. Thinking and working like a scientist: Application of knowledge to experimental research work.** For each item, students were asked to rate their level of gains "as a result of your lab-based experimental research experiences in your science class this

Table 4.28: The means and t-test for equality of means between those in the SRPP and those not in the program for the items comprising Factor 1

Items in SSRSSA Factor 1: Thinking and Working Like a Scientist	**SRPP Status**	**N**	**Mean**	**SD**	**Variance Equality**	**t-test (Sig.)**
1.1-Analyzing data for patterns.	Not in SRPP	29	3.83	1.17	Not Assumed	0.007**
	In SRPP	109	4.43	0.80		
1.2-Figuring out the next step in an experimental research project.	Not in SRPP	29	3.38	1.15	Not Assumed	0.001**
	In SRPP	108	4.2	0.75		
1.3-Problem-solving in general.	Not in SRPP	29	3.79	0.90	Assumed	0.003**
	In SRPP	108	4.25	0.73		
1.4-Formulating a research question that could be answered with data.	Not in SRPP	29	3.93	1.00	Assumed	0.026*
	In SRPP	108	4.29	0.83		
1.5-Identifying limitations of research methods and designs.	Not in SRPP	29	3.9	0.94	Assumed	0.009**
	In SRPP	109	4.3	0.78		
1.6-Understanding the theory and concepts guiding your research projects.	Not in SRPP	29	3.97	1.02	Assumed	0.028*
	In SRPP	109	4.28	0.72		
1.7-Understanding the connections among scientific disciplines.	Not in SRPP	27	3.41	1.12	Not Assumed	0.073
	In SRPP	105	3.75	0.89		
1.8-Understanding the relevance of the lab-based experimental research to the rest of the class content.	Not in SRPP	29	3.66	0.94	Assumed	0.001**
	In SRPP	108	4.21	0.80		

* Significant at the $p < 0.05$ level.
** Significant at the $p < 0.01$ level.

year." Because careful and complete analysis of the factor scores has already established the significance of the differences with high confidence, for the item analysis a simple t-test for equality of means along with Levene's test for equality of variances is adequate for this purpose.

The items in Factor 1 ask for students' assessment of their gains on a number of aspects covering most areas of experimental research work. It can be seen from Table 4.28 that almost all aspects questioned showed a difference in means between those in the SRPP and those not. Five of the items showed significance to the $p < 0.01$ level, two to the $p < 0.05$ level, with the last, understanding the connections among scientific disciplines close to significance, at $p = 0.073$. These results are unsurprising. The SRPP, with its requirement that students conduct original research with a possibility of publishing their findings being a focus of the lab component of the course, would be expected to have a positive effect on all aspects of experimental research addressed in the items.

Factor 2. Personal gains related to experimental research work was comprised of eight items, with students again being asked to assess their gains on each item "as a result of your lab-based experimental research experience in your science class this year." The results of the item-analysis are presented in Table 4.29.

For this factor almost all of the items show differences in means, with those in the SRPP being higher. Most of the items show very significant differences, with five at the $p < 0.01$ level. The items showing an effect are unsurprising, as they are related to the SRPP's focus on conducting original research to create new knowledge that can then be published. Items 2.1, 2.4, and 2.7 are especially important in preparing students to enter STEM fields, and seem unique coming from a secondary school program. Again, those items that did not show a difference, 2.2 and

Table 4.29: The means and t-test for equality of means between those in the SRPP and those not in the program for the items comprising Factor 2.

SSRSSA Factor 2 Personal Gains	SRPP Status	N	Mean	SD	Variance Equality	t-test (Sig.)
2.1-Confidence in my ability to contribute to science.	Not in SRPP	29	3.24	1.22	Assumed	0.030*
	In SRPP	109	3.65	0.99		
2.2-Comfort in discussing scientific concepts with others.	Not in SRPP	29	3.86	0.92	Assumed	0.218
	In SRPP	107	4.00	0.82		
2.3-Comfort in working collaboratively with others.	Not in SRPP	29	3.66	0.90	Assumed	0.004**
	In SRPP	109	4.16	0.90		
2.4-Confidence in my ability to do well in future science courses.	Not in SRPP	29	3.48	1.27	Not Assumed	0.007**
	In SRPP	108	4.12	0.83		
2.5-Ability to work independently.	Not in SRPP	29	4.03	0.94	Assumed	0.192
	In SRPP	108	4.20	0.93		
2.6-Developing patience with the slow pace of research.	Not in SRPP	28	3.32	0.98	Assumed	0.002**
	In SRPP	108	3.90	0.91		
2.7-Understanding what everyday research work is like.	Not in SRPP	28	2.96	1.23	Assumed	0.006**
	In SRPP	108	3.54	0.99		
2.8-Taking greater care in conducting procedures in lab work.	Not in SRPP	29	3.79	0.90	Assumed	0.001**
	In SRPP	109	4.33	0.78		

* Significant at the $p < 0.05$ level.
** Significant at the $p < 0.01$ level.

2.5, are not particularly surprising. Item 2.2, 'Discussing concepts with others', is never directly addressed by the SRPP so would not be expected to show an effect. And item 2.5, 'Working independently', is equally well addressed in a non-SRPP IB Physics course, where students regularly conduct traditional labs independently. Looking at the items individually has enabled us to develop a richer understanding of the effects of the SRPP, both areas in which it benefits students and in which there is no significant effect.

The next factor is **Gains in skills related to experimental research work**. Again, students were asked to rate their gains on each item "as a result of your lab-based experimental research experience in your science class this year." There were 13 items in this factor. The results are presented in Table 4.30.

Table 4.30: The means and t-test for equality of means between those in the SRPP and those not in the program for the items comprising Factor 3.

SSRSSA Factor 3. Gains in Skills	SRPP Status	N	Mean	SD	Variance Equality	t-test (Sig.)
3.1-Writing scientific reports or papers.	Not in SRPP	29	4.17	1.07	Not Assumed	0.010**
	In SRPP	109	4.68	0.59		
3.2-Making oral presentations.	Not in SRPP	28	2.82	1.22	Assumed	0.302
	In SRPP	99	2.69	1.21		
3.3-Defending an argument when asked questions.	Not in SRPP	29	3.41	1.15	Assumed	0.336
	In SRPP	108	3.51	1.06		
3.4-Explaining my research projects to people outside my field.	Not in SRPP	28	3.46	1.14	Assumed	0.255
	In SRPP	104	3.62	1.06		
3.5-Preparing a scientific poster.	Not in SRPP	26	2.50	1.21	Assumed	0.425
	In SRPP	85	2.45	1.26		
3.6-Keeping a detailed lab notebook.	Not in SRPP	27	2.41	1.01	Assumed	0.016*
	In SRPP	96	2.98	1.26		
3.7-Conducting observations in the lab or field.	Not in SRPP	28	3.57	0.88	Assumed	0.015*
	In SRPP	108	3.96	0.83		
3.8-Using statistics to analyze data.	Not in SRPP	25	3.60	1.16	Assumed	0.045*
	In SRPP	108	3.99	1.00		
3.9-Calibrating instruments needed for measurement.	Not in SRPP	29	3.21	1.08	Not Assumed	0.000**
	In SRPP	109	4.18	0.86		
3.10- Working with computers in collecting, analyzing, and presenting scientific information.	Not in SRPP	29	4.10	0.90	Assumed	0.003**
	In SRPP	109	4.57	0.77		

SSRSSA Factor 3. Gains in Skills	SRPP Status	N	Mean	SD	Variance Equality	t-test (Sig.)
3.11-Understanding journal articles.	Not in SRPP	21	3.10	1.04	Assumed	0.041*
	In SRPP	105	3.50	0.96		
3.12-Conducting database or internet searches.	Not in SRPP	28	3.36	1.39	Not Assumed	0.134
	In SRPP	107	3.67	0.99		
3.13-Managing my time.	Not in SRPP	29	3.07	1.31	Assumed	0.019*
	In SRPP	108	3.57	1.11		
* Significant at the p < 0.05 level. ** Significant at the p < 0.01 level.						

Like before, items that are addressed as part of the SRPP show significant differences. Items 3.1 and 3.6-10 are all important skills learned in doing original scientific research, and with SRPP students' increased ownership of and engagement in their experimental research projects, it is not surprising that they show increased gains. When the importance of these items to a students' future affinity to and ability in STEM fields is considered, it becomes obvious what a powerful and important effect the SRPP is having on students in ways that are very unusual at the secondary level. Items 3.2-3.5 are, again, aspects that are not directly addressed by the SRPP, so increased gains by SRPP students in these areas would come as a surprise.

Factor 4. Attitudes and behaviors related to experimental research work was comprised of eight items. The results of the analysis is presented in Table 4.31. There is a significant difference in gains, with SRPP students reporting increased gains at a significant level for seven of the eight items, all of which are an aspect of the approach and philosophy of the SRPP program. Again, looking at these items, it is hard not to get excited about what the SRPP does for science students still in secondary school: Engage in real-world science, Think creatively, Try out new ideas, Feel responsible for your project, Excited about the research, Feel a part of the scientific community.

Table 4.31: The means and t-test for equality of means between those in the SRPP and those not in the program for the items comprising Factor 4.

SSRSSA Factor 4. Attitudes and Behaviors	SRPP Status	N	Mean	SD	Variance Equality	t-test (Sig.)
4.1-Engage in real-world science research	Not in SRPP	29	2.90	1.05	Assumed	0.005**
	In SRPP	109	3.45	1.00		
4.2-Feel like a scientist.	Not in SRPP	29	2.90	1.15	Assumed	0.006**
	In SRPP	108	3.44	1.00		
4.3-Think creatively about your experimental research projects.	Not in SRPP	28	3.39	1.17	Not Assumed	0.003**
	In SRPP	109	4.08	0.92		
4.4-Try out new ideas or procedures on your own.	Not in SRPP	29	3.24	0.99	Assumed	0.005**
	In SRPP	109	3.82	1.06		
4.5-Feel responsible for your experimental research projects.	Not in SRPP	29	3.97	0.87	Assumed	0.009**
	In SRPP	109	4.39	0.84		
4.6-Work extra hours because you were excited about the research.	Not in SRPP	29	2.55	1.38	Not Assumed	0.006**
	In SRPP	109	3.29	1.13		
4.7-Interact with scientists from outside your school.	Not in SRPP	26	1.92	1.20	Assumed	0.389
	In SRPP	103	1.85	1.08		
4.8-Feel a part of a scientific community.	Not in SRPP	29	2.38	1.15	Assumed	0.031*
	In SRPP	109	2.80	1.04		

* Significant at the $p < 0.05$ level.
** Significant at the $p < 0.01$ level.

The fifth SSRSSA factor is **Your experience in your science class this year**. Students were asked to rate six items on a four-level Likert-scale from “Poor” to “Excellent”. The results are shown in Table 4.32.

All items here show very significant differences at the $p < 0.01$ level. Items 5.3, 5.4 and 5.6 seem to be important effects, most likely attributable to the SRPP. It is suggested however, as with the TOSRA Enjoyment of Science Lessons

Table 4.32: The means and t-test for equality of means between those in the SRPP and those not in the program for the items comprising Factor 5.

SSRSSA Factor 5. Experience in Science Class	SRPP Status	N	Mean	SD	Variance Equality	t-test (Sig.)
5.1-My working relationship with my Science teacher.	Not in SRPP	29	2.86	0.79	Assumed	0.000**
	In SRPP	108	3.56	0.57		
5.2-My working relationship with partners for lab-based experimental research.	Not in SRPP	29	3.10	0.56	Not Assumed	0.001**
	In SRPP	108	3.51	0.57		
5.3-The amount of time I spent doing meaningful research.	Not in SRPP	29	2.24	0.83	Assumed	0.000**
	In SRPP	109	3.01	0.73		
5.4-The amount of time I spent with my Science teacher talking about my experimental research.	Not in SRPP	28	2.04	0.88	Assumed	0.000**
	In SRPP	109	2.97	0.87		
5.5-The advice my Science teacher provided about university or careers.	Not in SRPP	22	2.14	1.04	Not Assumed	0.001**
	In SRPP	94	3.02	0.84		
5.6-The experimental research experience in Science class overall.	Not in SRPP	29	2.62	0.86	Assumed	0.000**
	In SRPP	109	3.57	0.55		

* Significant at the $p < 0.05$ level.
** Significant at the $p < 0.01$ level.

Factor, that items 5.1, 5.2 and 5.5 may have more to do with individual teachers and their personalities, rather than being a direct effect of the SRPP. Little confidence would be placed in concluding that these items were an *effect* of the program, rather than merely a *correlation*.

Examining the Non-Core Sections in SSRSSA

As described earlier, there were three non-core sections in the original URSSA instrument that were retained in the SSRSSA. These sections address a variety of areas and thus were not combined into defined factors. The items in these sections are analyzed individually. **Section 6. Affect of your experimental research experience on your attitudes toward the future** consisted of five items, and **Section 7. Motivation to participate in lab-based experimental research experiences in your science class this year** consisted of six. The last section, **Section 8**, consisted of three open-ended response items asking for further elaboration and explanation of previous topics.

Section 6 asked students to use a five-point Likert-scale to rate their agreement or disagreement with the statement "My lab-based experimental research experience in science class this year has…" for each item. The analysis for the items in section 6 is presented in Table 4.33.

All items in Section 6 showed a very significant difference in means ($p < 0.01$) between SRPP students and non-SRPP students. It is important to note that the student was asked to rate how their *experimental research experience in the course* affected each item. This was not a rating of the teacher's effectiveness, or the course content, or the course's overall effect, it was a rating of the *experimental research* aspect of the course. This is precisely the aspect of the course that is the focus of the SRPP, and SRPP students reported much higher results for all items. Students in the SRPP reported increased levels of preparedness for both scientific coursework and scientific research, as well is increased desire to pursue science studies and to get involved in scientific research at university. All these are important results for economies with shortages of qualified STEM-field workers.

Table 4.33: The means and t-test for equality of means between those in the SRPP and those not in the program for the items comprising Section 6.

SSRSSA Section 6 Future in Science	SRPP Status	N	Mean	SD	Variance Equality	t-test (Sig.)
6.1-Increased my desire to enroll in a university program in science, engineering or medicine.	Not in SRPP	28	3.11	1.10	Assumed	0.000**
	In SRPP	103	4.02	0.96		
6.2-Increased my desire to pursue a career in science, engineering, or medicine.	Not in SRPP	29	3.07	1.07	Assumed	0.000**
	In SRPP	104	3.83	1.04		
6.3-Prepared me for more advanced scientific research work.	Not in SRPP	29	3.34	0.86	Assumed	0.000**
	In SRPP	106	4.28	0.75		
6.4-Prepared me for more advanced scientific coursework.	Not in SRPP	29	3.69	0.81	Assumed	0.002**
	In SRPP	108	4.19	0.79		
6.5-Increased my desire to get involved in scientific research while at university.	Not in SRPP	29	3.17	0.89	Assumed	0.005**
	In SRPP	107	3.71	1.00		

* Significant at the $p < 0.05$ level.
** Significant at the $p < 0.01$ level.

Section 7, Motivation to participate in lab-based experimental research experiences in your science class this year, again asked students to rate their agreement with the statement "I wanted to participate in the experimental research experience in my science class this year in order to…" for each item. The results of the analysis are presented in Table 4.34.

Again, SRPP students showed significantly higher means for each item in this section. While at first glance the reasons for this are not evident, but upon further thought it does make sense. SRPP students are aware that their experimental research experience in the course is authentic, original, and may lead to the opportunity to have a paper published in an established scientific journal. Compare this to a traditional secondary science lab program in which, as a colleague likes to say with mild

Table 4.34: The means and t-test for equality of means between those in the SRPP and those not in the program for the items comprising Section 7.

SSRSSA Section 7 Motivation	SRPP Status	N	Mean	SD	Variance Equality	t-test (Sig.)
7.1-Explore my interest in science	Not in SRPP	29	3.72	0.92	Not Assumed	0.038*
	In SRPP	108	4.06	0.75		
7.2-Gain hands-on experience in experimental scientific research	Not in SRPP	29	3.72	0.88	Not Assumed	0.020*
	In SRPP	109	4.10	0.71		
7.3-Clarify whether I wanted to pursue a science-related career	Not in SRPP	28	3.32	0.98	Assumed	0.029*
	In SRPP	108	3.74	1.05		
7.4-Have a good intellectual challenge	Not in SRPP	29	3.83	0.89	Not Assumed	0.037*
	In SRPP	109	4.16	0.70		
7.5-Get good letters of recommendation	Not in SRPP	29	2.34	0.86	Not Assumed	0.036*
	In SRPP	103	2.70	1.10		
7.6-Enhance my college application resume	Not in SRPP	28	2.64	0.78	Assumed	0.032*
	In SRPP	107	3.05	1.07		

* Significant at the $p < 0.05$ level.
** Significant at the $p < 0.01$ level.

hyperbole, "They've been doing the same labs, with known results, for the last 100 years." It makes sense that SRPP students agreed more strongly with statements that reflected the challenges they had been offered and had successfully achieved. Items 7.1-3 are related to the more authentic research experience SRPP students know they are getting, and the positive results for items 7.4-6 are likely due to the fact that students understand that publishing a paper would be an important accomplishment that distinguishes them from other university applicants.

The final section of the SSRSSA instrument consisted of three open-ended responses, allowing respondents to elaborate on previous items or add other aspects that they felt were important to note. In order to triangulate the findings up to now, and to enrich our understanding of the effects of the SRPP, some of the more typical or important responses were selected and reviewed.

Many students emphasized the value of the program in terms of how it developed their skills and attitudes, preparing them for future studies and careers. The following are a selection of these, with commentary as appropriate. First a selection of SRPP student comments on the benefits of the program. We start with some comments on the skills they gained from the program.

> “I feel that the independent experimental research we did in IB physics did a very good job of teaching us how to think creatively and be problem solvers for an area of research each student was individually interested in.”
>
> “Doing the many researches and write ups that were expected of us is one of the most beneficial things for me in high school. Not only did I learn to write in detail, it also helped me improve my scientific writing skills by leaps and bounds.”
>
> “Our lab research taught us to be more analytical and always question why things work the way they do. It provided a great practice to question everything and think critically.”
>
> "The experience enabled me to acquire skills including the ability to think logically, to plan and practically execute an individually established idea and to create a professional account of an investigation. These skills can be applied to almost any area of study and I expect it to help me greatly in the future.”
>
> “From doing experimental research in IB Physics, I gained an ability to not only analyze data and conduct an experiment, but also to think critically, plan ahead, and manage my time. I also discovered an affinity for seeking and learning new knowledge, which was inspired in part by experimental research at ISB.”

Thinking creatively, critical thinking and analytical thinking, problem-solving, planning and executing projects, writing and communication skills, time management, curiosity: these are skills that many educators think are crucial for current students, skills students will need to be successful in the future. These are the qualities that the SRPP enhances in students.

The following are comments from SRPP students in the classes of 2010 and 2012, who were surveyed while they were in university. They describe how the program helped them in their studies at university.

> "When writing my bachelor thesis at University I used everything that I learned for writing the research papers in the IB Physics course."

> "One of the subtle things I gained from experimental work in IB Physics was an appreciation for uncertainties. When speaking to my peers in my engineering program here (at university), I think that's what their high school lab experience lacked the most. Since they were doing work that was prescribed, they were only concerned with getting the "right answer" not with whether this "right answer" is statistically significant. When I started in university research, it was all about uncertainties. We're only able to gain confidence in our work through uncertainty analysis."

These students also comment on how the program affected them personally.

> "It gave me a large sense of empowerment in wanting to explore new territories through experimentation. Although I am not currently pursuing a career in science, the hands-on approach that I experienced during my IB Physics class at ISB has stayed with me."

> "Research was a big part of the IB Physics class. It is one of my favorite parts of the class. Every time we did a lab experiment, I felt like I matured as a scientist."

> "I realized that as with any other study, there will come a point when you begin to create knowledge instead of learning what others have found."

> "The program forced me to get comfortable in the uncomfortable situation/reality where there is no clear-cut answer."

> "The freedom we were given with the IRPs really helped me to gain interest in science. But when I got to university, such freedom of research is not allowed, which really is frustrating for me."

Finally, here are some comments on how the SRPP influenced these students' decisions for their future directions.

> "Through research, I became more interested in the idea of applying Physics to real life situations. It even helped me decide that I wanted to study engineering and constantly be exposed to the application of science at university"

> "My research done at ISB motivated me to pursue a career in health-care because it involved a lot of hands-on experiences with various instruments, collecting data with those instruments, and understanding why or how that data came to be."

> "I believe the program was successful in portraying the reality of research, and this helped me by allowing me to realize early on that research was not a good fit for me."

> "It allowed me to realize that I love the process of questioning, designing an experiment and making discoveries."

> "By carrying out experimental research, it was really fundamental in convincing me I had the ability to carry out scientific research in the future, even if it would not necessarily be in the field of physics."

Both those who did and those who did not end up going into a science-related field found that the SRPP was valuable in introducing them to the realities of science and what a career in STEM would be like. It helped them decide if they were interested in pursuing studies and a career in this field or not.

From the analysis of the results of the SSRSSA instrument, it is clear that the SRPP has an important, positive effect on a wide range of student research skills and attitudes, provides them with insights not directly related to research, and helps clarify future directions. It is now time to turn to the analysis of the fourth survey instrument used in this study.

Development of the AESP: Investigating Effects of the Publishing Aspect of the SRPP on Students

The SSRSSA, being adapted from the URSSA, focused exclusively on the experimental research part of the Student Research and Publishing Program. It was decided that an instrument that could also gather information on the effects of the publishing part of the program was needed. This instrument, the Attitudes toward and Effects of Student Publishing (AESP), was developed for use in this study. The development of the instrument is described in more detail in the previous chapter. After development, the instrument was validated by six experts, using the form shown in Appendix C.5. The experts, whose qualifications are described in the previous chapter, were asked to rate each question's Item-Objective Congruence (IOC) as "Valid" (1), "Unsure" (0), or "Invalid" (-1), including comments and suggestions for improvement of the instrument. The summarized results of the expert validation ratings are shown in Appendix C.6. Only one item received a rating below 0.5, with three items at 0.5, all due to one of the validator's "Invalid" rating on these items. This validator, an EAL (English as an Additional Language) expert, indicated that the issue was with the wording of the items. The items were revised and the validator then approved the items individually. Other items were revised based on the comments of the experts as appropriate. All six experts gave their approval of the validity of the questionnaire as a whole.

The AESP was tested for reliability using Cronbach's alpha with the results shown in Table 4.35. The number of respondents used for the reliability test was smaller than recommended due to the fact that there are only 37 students who have published papers in the *JoS*, limiting the potential sample size. Even with that limitation, both sections of the instrument showed acceptable levels of reliability of above 0.70 (Santos, 1999).

Table 4.35: The results of the reliability test for the AESP Instrument

Reliability Test	N	N of Items	Cronbach's alpha
Scction 2: Effects of the Possibility of Publishing	20	7	0.960
Section 3: Effects of the Process of Publishing	20	6	0.795

The final version of the AESP, presented in Appendix C.7, consists of both Likert-type and open-ended questions. The Likert-type questions were based on a four-point scale with the choices “No effect”, “Little effect”, “A moderate effect”, and “A great effect”. Since the survey asks about the effects of the publishing aspect of the program, it was administered only to the Treatment Group, students *in* the SRPP, and not to students in the Control Group. As such, comparisons between the means of the two groups cannot be made, as was done for the previous three instruments. A discussion of the descriptive statistics for the Likert-type items will be followed by presentation of findings from open-ended questions.

Descriptive Statistics and Discussion of Open-ended Responses

The first section consisted of two questions inquiring about the respondent’s level of interest in publishing a paper in the *Journal of Science*. These will be addressed after looking at sections 2 and 3.

Effects of the possibility of publishing. The descriptive statistics from section 2 of the instrument are presented in Table 4.36. Section 2 attempts to measure how much the possibility of having their work selected for publishing affected the students’ efforts in various aspects of the research process. The results show means for each aspect ranging from approximately 2.4 to 2.7, corresponding to means between the responses of “Little effect” and “Moderate effect”. This result seemed, to the author, surprisingly low. This will be discussed later.

Table 4.36: Statistics describing responses to section 2 of the instrument.

Section 2: To what extent did the possibility of publishing affect…	N	Mean	Interpre-tation	SD	Percent Responses >= 3
2.1- ….your effort in choosing a research question for your IRP's?	95	2.44	Little effect	1.01	50.5
2.2- ... your effort in finding and understanding background theory for your IRP's?	96	2.40	Little effect	1.02	50.0
2.3- ... your effort in designing your experimental setups and methods for your IRP's?	96	2.39	Little effect	1.06	42.7
2.4- ... your level of care and attention to detail when conducting for your IRP's?	95	2.68	Moderate effect	1.06	62.1
2.5- ...your willingness to spend extra time outside of class to ensure valid results for your IRP's?	95	2.60	Moderate effect	1.04	58.9
2.6- ... your effort in the processing and analysis of data for your IRP's?	95	2.59	Moderate effect	1.12	57.9
2.7- …your effort in writing the report for your IRP's?	96	2.55	Moderate effect	1.08	58.3
IRP = Independent Research Project					

The standard deviation for each of the items was relatively high, indicating a wide distribution in student responses across the scale. This was confirmed by looking at the frequency tables for each item, (not included in the interests of space), with responses being fairly evenly distributed across the four levels. The proportion of students responding with either moderate effect or great effect ranges between approximately 40% and 60%, in line with expectations from the mean and standard deviations.

We now return to the question of why the responses to section 2 were lower than expected. Looking at student responses to item 2.8, which asks respondents to elaborate on their answers to 2.1-7, the results make more sense. The following are selected quotes representative of the range of responses.

> "I always tried my best to write a decent, well structured, and well written lab report. The thought of having the paper published probably motivated me a bit further to achieve that, but its effect was definitely limited."

> "I did my independent research for my IB physic's (sic) class not for the sake of the *Journal of Science*."

> "It is my nature to produce my highest caliber work for all assignments that matter to me, regardless of the potential for public dissemination and/or recognition. However, the possibility of being published certainly offered an additional element of excitement."

> "I didn't feel like the possibility of publishing a paper was forefront in my mind when designing or executing the experiment. I chose a topic that I was interested in, regardless of whether it would be a publishable experiment or not, and I spent a lot of time on the experiment because I wanted to know the answer to the question that I myself had posed."

> "The possibility of writing a paper made me try and think of interesting research questions, however when I was actually writing the lab report, I didn't put any extra effort to be able to write a paper because I try to put a lot of effort into my lab reports either way, so the possibility of writing a paper didn't make a difference."

These help explain the lower-than-expected means on the items in section 2. While the *JoS* is a necessary and integral part of the program as a whole, serving as the end-point of the scientific process, most students do not focus on it when designing and conducting their research, which is a required part of the course. Rather, students seem to be motivated to put in their best efforts on this due to personal character or their desire to do well in the course.

These results can be further illuminated by returning to look at the results of section 1, which asked for students' level of interest in publishing using a five-point scale ranging from "not interested at all" to "extremely interested". Students were also asked to explain their response. The responses here parallel the responses to section 2. The mean of the responses was equivalent to the middle choice, "interested", with a similarly large standard deviation of 1.2, and only 33% of respondents choosing the 'very' or 'extremely' interested.

At this point, it would be instructive to look at the correlations between some of these variables. Calculating the Pearson Correlation showed that the average response of the items in section 2 (effect of the possibility of publishing on student effort) was strongly correlated with student interest in publishing ($r = 0.474$). Unsurprisingly, the Science and Math Coefficient was also shown to be strongly correlated to student interest in publishing ($r = 0.511$). Academically stronger science students seem more interested in publishing, and that interest more strongly motivates their efforts in designing and conducting independent research.

Responses from students who showed little interest in publishing were also illuminating.

> "Since my level of interest in physics was not extremely high, it would be difficult to spend the required time and effort to publish a good paper. Hence, I was not very interested (in the possibility of publishing)."

> "I would have been more interested in publishing a paper if I felt that my work was worth publishing and if I had more free time to do so with a full IB course load."

> "It was a lot of extra work and I wasn't sure if writing scientific papers was something I'd do much in the future."

> "(At) the beginning of my IB physics class, I can say I was not very keen on publishing a paper because I did not know much about the potential benefits."

Reasons offered include: lack of interest in the field, an awareness of the extra demands of the publishing process coupled with lack of time, and a lack of understanding of the benefits. These were typical responses among those with little interest in publishing. The last quote, lack of understanding of the benefits, is interesting. As will be seen later, many students who were in university when surveyed reported that their view of the importance of publishing changed after getting to university. It seems that many secondary school students have little understanding of the value of the SRPP while in the course, but gain greater appreciation as they mature.

Students who reported high levels of interest commonly explained their positions as follows:

> "It was a fantastic opportunity for me to make an impact on something larger than myself, my grades, or my teacher, and it was a chance to take away something concrete and lasting from my experience with physics. It was also a great opportunity for me to understand the process of publishing something peer-reviewed and vetted in the real world - a chance to expand my education with a tangible real-world experience."

> "I knew that if I was going to be scientist in the future, I would need to practice writing papers for a journal."

> "A unique opportunity to write a scientific paper before entering university."

> "Publishing a paper is an honor. The experience of writing a near-professional paper, publishing it, and being a part of the scientific community made me extremely interested."

> "Prestige of having published would look good on a college application."

For the one-third of the students who were very interested in publishing, the opportunity was recognized as a way to challenge themselves in a unique and rigorous way, to gain experience in a new skill, and, of course, being practical, to enhance their university applications. We can conclude that, while the possibility of publishing seems to mostly motivate the academically stronger students, for those students it is a powerful motivator.

The final item in section 2 asked students who were surveyed while at university to describe if and how their views of the value of the *Journal of Science* had changed since they had been in the course. Approximately 40% of respondents said that their views had changed. The following are some of the typical responses:

> "I realize how important having a published paper is in the academic world now, and how favorably it is looked upon. I wish I had understood this earlier."

> "After attending university as a physics major, I realized the power of publication. Any published work, no matter how light or funny the questions may seem, holds much value in terms of credibility. In high school, I simply did not know the magnitude of integrity the published work carried compared to 'lab reports'."

> "When you do it (publish a paper) in high school you barely understand why you are doing it and its impact on science. This is because you don't know what science is like at the professional level."

> "Unsurprisingly, I think I didn't fully appreciate the value of the *Journal* as a highschooler (sic). Four years later, and now having taken advanced courses in science that emphasize primary literature, I see how beneficial it was for me to go through the experience of publishing the results of even a simple physics experiment. As I now have a clear desire to go into research, I'm glad to have had the chance afforded by the *JoS* program."

> "When attending University, I viewed the value of the *Journal of Science* to be greater in terms of developing my abilities to do research. The main reason is that I have been doing independent research while at University and the experience of publishing a paper in the *Journal of Science* helped me be more prepared for the individual research. Also, publishing a paper in the *Journal of Science* aided my ability to write concisely which has been helpful while at University for my individual research."

It is interesting that the value of the *Journal of Science* program is not fully recognized by students while in the program. While students currently in the program do see it as valuable, due to their lack of experience they do not recognize the full extent of its value. One final quote from a student, now in his fourth year of university, regarding his estimation of the value of the *Journal of Science* is as follows:

> "The *JoS* was one of the most important aspects of ISB's science program when I was there. All the other aspects (IRPs, rigor, etc) are necessary, but the *JoS* takes all of that and ties it together into one crown jewel. Because of the experience I had with the independent research projects and subsequently the *JoS*, I understood what research could entail. I knew what it was like to pursue a question in lab and validate that question, not with a "back of the book answer," but with theory and confidence in my work. That allowed me to start working at a research

> lab at university by the second semester of my freshmen year. For students wanting to go into a research field, the work leading up to and during the *JoS* is probably the best training they can get in high school."

A 'crown jewel'! Clearly this student sees publishing in the *Journal of Science* as a crucial aspect of the SRPP, tying it together. An educator would, after studying the SRPP, see that the existence of a journal is crucial for the SRPP as a goal, an endpoint, a critical component which completes the model and ties it all together. It is impressive that a student going through the program has had that insight. The student's description of the process of scientific research, and the understanding of the role and the value of each part of the SRPP in that process, is also accurate and insightful.

Effects of publishing a paper. Section 3 of the AESP instrument was administered only to students who had actually published a paper in the *JoS* (N = 29 out of a total SRPP sample of N = 112). It begins with an item asking students to estimate the number of hours they spent on the publishing process. The next six items address the effect of the publishing process had on various research skills. Students were asked to rate each item using the same four point Likert-scale used in section 2. The last two items were open-ended questions asking students to elaborate on their responses.

The first item showed answers ranging from 10% of respondents saying "Less than four hours" to 20% of respondents saying "More than 16 hours", with a mean indicating an average of about 10 hours spent on the publishing process. It is important to note that this time does not include the design, conduct, and data analysis of the in-class, independent research project or the time spent writing the lab report. All of these are required parts of the course. The 10 hours reported by students is only the time spent writing and revising the *Journal* paper itself.

The results to the next six items are shown in Table 4.37 on the following page. Unsurprisingly, the means of the student responses to these items were high, with most being around 3, and one, scientific writing ability, at just below 3.5 on a 4-point scale. Approximately one-third of students responded that publishing had “a great effect” for all the items except one. Scientific writing ability showed a much higher result, with 60% of students saying that the publishing process had “a great effect.” These seem to be important effects, given the fact that it was only a 10-hour time investment during a two-year program, and a quarter of students in the SRPP sample experienced these benefits.

Table 4.37: Statistics describing responses to section 3 of the instrument.

Section 3: To what extent did the process of publishing a paper in the *Journal of Science...*	**N**	**Mean**	**Interpre-tation**	**SD**	**Percent Responses = 4**
3.2- …improve your ability to analyze experimental data?	29	3.00	Moderate effect	0.89	31
3.3- …improve your ability to draw valid and justified conclusions from scientific data?	26	3.31	Moderate effect	0.68	39
3.4- ...improve your ability in the visual presentation (figures and graphs) of your results?	29	3.00	Moderate effect	0.80	28
3.5- ...improve your ability to understand scientific papers related to your research?	23	2.96	Moderate effect	0.83	30
3.6- ...improve your scientific writing ability?	29	3.48	Moderate effect	0.74	59
3.7- …increase your desire to publish a scientific paper in the future?	29	3.07	Moderate effect	0.84	35

The student comments elaborating on these ratings provide a richer understanding of the gains achieved by the students in the publishing process:

> "Publishing a paper in the *Journal of Science* developed my ability to write for scientific and academic assignments while at University."

> "(It) greatly helped with my scientific writing. I learned so much about how to write a (scientific) paper while writing the paper."

> "The (publishing process) has forced me to read scientific papers that are much too complex for me to comprehend fully, so I have learned to parse information from these papers in the best way that I could."

> "(It) was the first taste I had of condensing my research and really digging in at the essentials."

> "It took five drafts to finally publish my paper. Through those five drafts, I was able to see what kinds of mistakes I was making as a student, and I made sure to note those flaws and never make them again. Thus, this sped up the process of writing lab reports, as I knew exactly what was required of a scientific paper. The continuous pattern of adding images, analyzing data, concluding, etc, allowed me to become better in those areas with writing reports not only in Physics, but also in Chemistry (and later on in the IB Math Internal Assessment). In addition, I learned to understand scientific papers better after struggling to interpret one that was the foundation of my own paper. Since I was able to go through the publishing process myself, I was able to better understand the structure of published papers."

The process of publishing a scientific paper is complex, and students who experience it gain a range of sophisticated skills. While not all students in the SRPP publish a paper, students who do take up this challenge benefit tremendously.

The final item in this section asked students to describe their reaction to learning that they were being invited to publish a paper in the *JoS*. Responses included pride, enthusiasm, and apprehension, with the most common being excitement. "I was very excited, because it meant that my work would be of actual scientific value." "I felt really excited! I thought to myself that I finally get to be a 'real scientist' with work that has my name on it. I could google my name and have something academic show up."

The last section of the AESP attempted to determine the effect that the SRPP had on students' participation in scientific research during university. With few responses to these items, nothing can be concluded as to the statistical effects of the program on participation in research at university. However, student responses are interesting. Some students said that the program had no effect on their participation in university because “the dissertation is a mandatory part of my degree” or “I had one professor tell me that they never turn away a student looking for research.” Others perceived it as having a greater effect: "being published once encouraged me to seek out other opportunities to continue to do proper research”, and “A taste for research left me hungry for more.” It appears that the attitudes, experience, and skills that students gain from the SRPP gives some of them the desire and the confidence to participate in research at university.

The results of the AESP instrument have shown that the *Journal of Science* itself and the possibility of publishing has little direct impact on some of the students in the program. Yet it is recognized as a crucial component of the program, providing an end point to the model of the scientific process upon which the program is founded. The results also show that, for academically strong and/or motivated students, the possibility of publishing is recognized as a valuable motivator, and for those who do publish a paper, gains are seen over a range of important and sophisticated skills. One final quote ends the analysis of this instrument:

> “Publishing a paper for the *Journal of Science* is one of the highlights of my high school education and I feel very grateful for having had that opportunity.”

Results

Objective 3. To Determine the Effect of the SRPP on Students' Research and Publishing Skills and Attitudes.

The data analysis of the two instruments administered for Objective 3 shows that, unlike for the first two objectives, there was a strongly significant increase in virtually all aspects of SRPP students' research and publishing skills and attitudes, compared to those not in the SRPP. The thematic analysis of the qualitative data supported these findings and offered a deeper understanding of the reasons for the difference. The qualitative responses indicated that student understanding of the goals of the course, based on the simplified model of the scientific process used in the SRPP, had a strong impact on students. Student enthusiasm and engagement caused by the authenticity of the original research experience, which happened within the context of awareness of the *Journal of Science* and the possibility of publishing their work, was also an important factor, according to the qualitative analysis. To summarize, the students in the SRPP showed higher levels of all research skills and attitudes measured, compared to those not in the SRPP. And the reasons for this difference were shown to be due to the nature of the SRPP itself.

Due to the fact that students not in the SRPP had neither the opportunity to publish, nor the experience of publishing, the AESP was administered only to students in the SRPP. The results of the AESP show that students who published a paper in the *Journal* reported important gains in publishing-related skills and attitudes, and attributed these to their experience in the SRPP program.

It is now time to look at the fourth objective investigating the effects of the established SRPP at ISB.

Data Analysis

Objective 4. To determine the effect of the SRPP on students' development of 21st Century Skills.

A series of complex and sophisticated skills have been identified as crucial for success in the 21st Century economy (Trilling & Fadel, 2009). Several of these were previously identified as possibly being affected by participation in the SRPP. While it is admittedly difficult to formally and quantitatively assess for the level of these skills in students by looking at work produced by students (Silva, 2009), it will be attempted here through an analysis of student lab reports.

To review, the purpose of the data analysis for Objective 4 is to determine the effects of the SRPP on students' development of 21st Century Skills. The Independent Variable is 'Participation in the SRPP', with the Treatment Group enrolled in an IB Physics course with the SRPP integrated into the course, and the Control Group enrolled in an IB Physics course with no SRPP. The Dependent Variable for Objective 4 is students' development of 21st Century Skills as measured by a rubric-based assessment of students' Lab Reports for their Independent Research Projects. The results of the rubric-based assessment are triangulated and enriched by the results of the thematic analysis of the open-ended responses to the SSRSSA and AESP instruments. The method of the data analysis used to accomplish the purpose is to compare the means of the results of the two groups in the study using a t-test, with qualitative data from the thematic analysis explaining and enriching the understandings of the results. The expected result of the data analysis is a determination of whether there is a significant difference in students' development of 21st Century Skills between the two groups being studied.

A sample of eight lab reports produced for Independent Research Projects (IRP's) by students in an IB Physics course at ISB that did not have the SRPP

(Control Group) and eight reports by students in an IB Physics course using the SRPP (Treatment Group) were selected. The eight reports from each group were obtained through random purposeful selection, so that the IB Internal Assessment scores matched for each pair, and so that there was a range from the highest to the lowest possible IB scores in the sample.

An outside expert, familiar with both the IB Physics program and the SRPP, anonymously assessed the reports for the 21st Century skills using the rubric shown in Appendix D. Each item in the assessment was rated on a 5-point Likert-scale from "not at all" (1) to "a great deal" (5). The author is the first to admit that any conclusions regarding students' development of 21st Century Skills drawn from this data must remain tentative. The process of assessing a student's level of attainment in these areas through the use of IRP lab reports is, to quote the expert who conducted the assessment, "not easy". However, it was felt that a tentative attempt was better than no attempt, as long as the results are acknowledged as being tentative.

Descriptive Statistics

The results of the analysis are presented in Table 4.38. Looking at the results, it can be seen that a number of the items show a much higher mean for students in the SRPP, with some showing a mean that is a little higher, and some having equal means. Due to the small number in the sample, and the large standard deviations, little can be concluded from this.

Table 4.38: The results of the analysis of lab reports for selected 21st Century Skills.

Aspect of '21st Century Skills' Demonstrated in Lab Report: The report demonstrates…	SRPP Status	N	Mean	Interpre-tation	SD
1. Creativity in experimental design.	Not in SRPP	8	1.38	Not at all	0.52
	In SRPP	8	2.75	Some	0.89
2. Innovation in the implementation of the design.	Not in SRPP	8	1.13	Not at all	0.35
	In SRPP	8	2.13	A little	1.36
3. Problem-solving skills in the conduct of the investigation.	Not in SRPP	8	1.75	A little	0.46
	In SRPP	8	2.25	A little	0.46
4. Critical thinking in analysis and evaluation of the results.	Not in SRPP	8	2.25	A little	0.71
	In SRPP	8	2.88	Some	0.99
5. Effective communication appropriate to the purpose.	Not in SRPP	8	3.38	Some	0.52
	In SRPP	8	3.63	A fair amount	0.52
6. Collaboration by appropriately placing itself within the context of others' research.	Not in SRPP	8	1.25	Not at all	0.46
	In SRPP	8	1.75	A little	1.04
7. Information literacy in accessing, evaluating, and using information from a variety of sources.	Not in SRPP	8	2.00	A little	0.76
	In SRPP	8	2.00	A little	1.07
8. ICT literacy in use of technology to create, organize, and communicate information.	Not in SRPP	8	2.88	Some	0.64
	In SRPP	8	3.00	Some	0.76
9. Flexibility, initiative, and independence.	Not in SRPP	8	1.88	A little	0.35
	In SRPP	8	2.75	Some	1.17

Testing for Differences of Means

A t-test for equivalence of means, along with Levene's test for equality of variance, was conducted on the data. The results are shown in Table 4.39. It can be seen from Table 4.39 that students' development of some of the 21st Century Skills assessed showed significant differences between the two groups, while others did not. These results will be discussed below.

Table 4.39: The results of the t-tests on the analysis of lab reports for selected 21st Century Skills.

Aspect of '21st Century Skills' Demonstrated	Levene's Test (Sig.)	Equality of Variance	t-test for Equality of Means (Sig.)
1. Creativity in experimental design	0.07[a]	Not Assumed	0.002***
2. Innovation in the implementation of the design	0.00[a]	Not Assumed	0.039**
3. Problem-solving skills in the conduct of the investigation	1.00	Assumed	0.025**
4. Critical thinking in its analysis and evaluation of the results	0.65	Assumed	0.084*
5. Effective communication appropriate to the purpose	1.00	Assumed	0.175
6. Collaboration by appropriately placing itself within the context of other's research.	0.15	Assumed	0.117
7. Information literacy in its accessing, evaluating, and using information from a variety of sources.	0.44	Assumed	0.500
8. ICT literacy in its use of technology to create, organize, and communicate information.	0.80	Assumed	0.364
9. Flexibility, initiative, and independence.	0.01[a]	Not Assumed	0.037**

a Equality of Variance can not be assumed.
* Significant at the $p < 0.10$ level.
** Significant at the $p < 0.05$ level.
*** Significant at the $p < 0.01$ level.

Results

Objective 4. To determine the effect of the SRPP on students' development of 21st Century Skills.

Five of the items show the SRPP students with a statistically significantly higher mean. These include

1. Creativity in experimental design, ($p < 0.01$)
2. Innovation in the implementation of the design, ($p < 0.05$)

3. Problem-solving skills in the conduct of the investigation, ($p < 0.05$)
4. Critical thinking in its analysis and evaluation of the results, ($p < 0.10$) and
9. Flexibility, initiative, and independence. ($p < 0.05$)

This result is not surprising. SRPP students are encouraged to create new knowledge in their research, with a focus on modeling the scientific process. They thus tend to choose unique topics of personal interest, which are more likely to demonstrate the characteristics in items 1, 2, 3, 4, and 9. Non-SRPP students in IB Physics are often limited by the teacher in their choice of topics for the IRP, with the primary aim being scoring well on the IB assessment rather than having students experience an authentic scientific process.

Items 5-8, **Effective communication, Collaboration by appropriately placing itself within the context of others' research, Information Literacy,** and **ICT Literacy**, showed no or small differences in means. Again, upon reflection, this is not surprising. IB Internal Assessment requirements for a lab report mean that students must have these skills in order to score well on the IB-assessed report, and since the samples were selected to have equal IB Internal Assessment scores, it is to be expected that the results of the analysis show no differences in means in these areas.

Tentative conclusions can be drawn that participation in the SRPP increases student development of certain of the 21st Century Skills, including Creativity, Innovation, Problem-Solving, Critical thinking, and Flexibility, initiative and independence.

Summary: Objectives 1 – 4: Effects of the Student Research and Publishing Program on four aspects of student skills and attitudes

It has been shown that the SRPP established in the Physics program at International School Bangkok increases students' attitudes and abilities in five important areas:

1. Thinking and working like a scientist: Application of knowledge to experimental research work,
2. Personal skills related to experimental research work,
3. Skills related to experimental research work,
4. Attitudes and behaviors related to experimental research work, and
5. Experience in science class related to experimental research work,

Further, it has been shown that the SRPP increases students' desire to pursue further studies in STEM fields as well as their preparedness for those studies. From student comments on open-ended responses, as well as analysis of lab reports, improved creativity, innovation, critical thinking and analytical thinking, problem-solving, planning and executing projects, writing and communication, time management, and curiosity were identified as benefits of the program.

It has also been shown that the publishing aspect of the Program, with an established entry-level Journal in which students have the opportunity to publish papers, is crucial to the program. It has an important and long-lasting impact on a variety of important and sophisticated skills that are applicable across a range of academic and professional fields. The publishing aspect of the program has been shown to have the greatest effect on academically stronger and/or more motivated students who want to challenge themselves. The ability to write scientifically and the desire to continue in research were identified as important benefits of the publishing process.

A number of areas which are important educational goals of science courses, but in which the Program has no significant effect, were also identified. These include, firstly, students' science-related attitudes, as measured by the TOSRA instrument. The SRPP students showed no difference in attitudes toward the Social Implications of Science and the Normality of Scientists, the Attitude to Scientific Inquiry and the Adoption of Scientific Attitudes, and Leisure and Career Interest in Science, compared to students who experienced the standard inquiry-based IB Physics program at ISB.

A second area, important to science education, but unaffected by the SRPP, was students' understanding of the Nature of Science. Students in the SRPP demonstrated no significant differences in understandings of aspects of NOS such as Observations and Inferences, Change of Scientific Theories, Scientific Laws vs. Theories, Social and Cultural Influence on Science, Imagination and Creativity in Scientific Investigations, and Methodology of Scientific Investigations, compared to students experiencing the standard IB Physics course at ISB.

Now that the value, benefits, and limitations of the Student Research and Publishing Program at International School Bangkok have been established, it is time to address the fifth objective of this project: Development of a Model for Implementation of the SRPP.

Data Analysis

Objective 5: Development of a Model for Implementation of a Student Research and Publishing Program in Secondary School Science.

To review, the purpose of the data analysis for Objective 5 is to develop a validated Model for Implementation of the SRPP in a new school. There were two main components to the method of the data analysis used to address this objective.

The first component consisted of conducting a two-year Trial Expansion of the SRPP into Biology and Chemistry at ISB. The purpose of the Trial Expansion was to provide a case study for implementation of the SRPP. It was expected that knowledge gained from studying the implementation process and student outcomes of the Trial Expansion would yield findings that could be used to inform the development of the Model for Implementation of the SRPP.

At the end of the two-year Trial Expansion, interviews were conducted with the implementing teachers to determine their perceptions of the strengths and weaknesses of the Trial Expansion process. The results of the interviews were analyzed using inductive thematic analysis. The students participating in the Trial Expansion responded to the same four survey instruments used in the first part of the study. Statistical analysis, including descriptive statistics and multivariate analysis of variance, was used, in the same way as in the first part of the study.

For the second component of the approach to this objective, interviews were conducted with a range of experts and participants in the established SRPP at ISB. The interview transcripts were analyzed using inductive thematic analysis. The findings of the analysis of both components were used to build a draft Model for

Implementation. The draft Model was subject to validation by experts and the expert feedback used to revise and finalize the Model.

The expected result of the data analysis is development of a validated Model for Implementation of the Student Research and Publishing Program in a new school. The Model is expected to be structured into several sections. The first section is expected to address the issue of the conditions necessary at a school in order to successfully implement the SRPP. This section will aid schools in making a decision as to whether the SRPP is appropriate for their school or not. The next section will look at the steps necessary to prepare for implementation of the SRPP. This section is expected to address aspects including teacher selection and training, establishing the Journal, and preparing the curriculum and students. The final sections are expected to address the implementation phase, describing the steps needed to successfully introduce, establish, and eventually, expand the SRPP in the school.

Trial Expansion of the SRPP into Biology and Chemistry: Analysis and Results

Review of the plan for the Trial Expansion. As explained in Chapter 3, in August, 2012, a trial expansion of the SRPP was begun. The program was introduced into IB HL Biology and IB HL Chemistry. Like IB Physics, these are two-year courses starting in Grade 11. On the first day of class, the teachers introduced the simplified SRPP model of the scientific process, described the *Journal of Science* and presented students with the possibility of publishing the results of the IRP's that they would be conducting near the end of year one and into year two of the course. Teachers were expected to remind students of the possibility of publishing at the beginning of each round of IRP's. The results of the expansion would be studied using two approaches.

Firstly, the two teachers implementing the trial expansion of the program would be interviewed in June 2014, at the end of the two-year course. The interviews would be inductively analyzed for themes indicating the strengths and weaknesses of the methods used in the trial expansion of the program. These results would be used to inform the development of the Model for Implementation of the SRPP.

Secondly, students in the trial expansion population would be asked to respond to four surveys, TOSRA, SUSSI, SSRSSA, and AESP in April 2014, near the end of the course. These were the same instruments used to with students in the established SRPP in Physics. The responses of students in the SRPP Trial Expansion would be compared with students in IB Biology and IB Chemistry classes who had not participated in the Trial Expansion. Also, the number of papers published by students in the trial expansion population would be noted and compared with the number of papers published by students in the established SRPP in Physics during the same time period.

The outcomes of each of these approaches will now be analyzed. It must be kept in mind that the Trial Expansion was implemented in August 2012. At that point in time, little analysis of the process of implementation of the SRPP in a new situation had been done. Little thought had been put into the conditions and characteristics needed for successful implementation of the SRPP. Also, the majority of the Trial Expansion course was completed before the model development interviews (discussed in the next section) had been conducted and analyzed. In hindsight, it is obvious that the Trial Expansion was implemented with inadequate thought and planning.

Trial Expansion teacher interview. In June 2014, the two teachers who had implemented the Trial Expansion into Biology and Chemistry were asked to complete a written-response interview. The instrument, shown in Appendix E, asked a series of questions about what the teacher felt had been the strengths and weaknesses of the Trial Expansion process. Questions addressed both the process of implementation of the SRPP, and the establishment of a culture of research and publishing among the students during the Trial Expansion. The respondents were asked to focus on both their role in the process and on the role of the author, the Editor of the *Journal of Science*, who acted as the "consultant", periodically advising the teachers on the implementation process during the two years. Due to unforeseen circumstances, only one of two teachers, the Biology teacher, was able to respond to the interview. The key findings from that response are shown in Table 4.40 below.

Looking at the findings of the implementing teacher response, it is clear that, while the start of the process was well done, with a strong SRPP introduction session at the beginning, there were a number of issues with the Trial Expansion. The Trial started with the confusion of an unavoidable roster reshuffle after the SRPP introduction session, resulting in teacher discouragement and a loss of momentum. Several additional issues were also identified. It was felt that inadequate emphasis of the SRPP was provided, with reminders and discussion not being offered regularly enough. An archive of previous student research that was published or publishable would have helped students understand the nature and level of work published in an entry-level Journal, and would have helped them embrace the challenge. Finally, inadequate support was offered to students in choosing research topics. A list of research areas likely to yield publishable results was not provided, as is done in the established SRPP in Physics.

Table 4.40: Key Findings and Themes from Implementing Teacher Interview on the process used to implement the Trial Expansion of the SRPP into Biology and Chemistry.

Topic	Key Findings and Themes
Strengths: **Implementing Teacher**	Initial introduction lecture was well prepared and well delivered.
	Continued to refer to the *Journal* before IRP's and spoke with students when a decent looking paper turned up.
	Independent research is already well established. Students carried out 4 complete, original, independent research experiences over 2 years.
Implementation Issues/Areas for Improvement: **Teacher**	Failed to actively steer students toward research that would likely be publishable or take the time before IRPs to generate ideas.
	Insufficient discussion and reminders about the *Journal* after the initial pitch especially in the few months following.
	Offer more support to enable students to choose publishable topics.
	Refer to the *Journal* more – this will be easy now that I have thought about it a lot more and have a little bit more experience.
	Did not allot adequate time to edit the paper during the publishing process.
	Did not do enough to establish a culture of publishing, beyond talking about it a few times and approaching a few students about publishing their reports.
Strengths: **Consultant**	Helped implementing teachers prepare the initial introduction of the SRPP.
	Identified and Prepared Reviewers. Supported with editing the first paper.
	Suggested keeping a list of research areas that are likely to yield publishable results for each discipline.
	Generally was a strong advocate for original, independent research.
	Maintained the *JoS* online so that it could easily be shown to students.
Implementation Issues/Areas for Improvement: **Consultant**	Establish guidelines to encourage implementing teachers to more regularly remind students of the *Journal* and the SRPP. This would assist in keeping it firmly at the front of instructional planning.
	Offer additional support in developing exemplars for student reference.
	Offer additional support in developing lists of research areas likely to yield publishable results to help guide students in topic selection.
	Offer additional support in screening and selecting IRP's for submission for review the first few rounds.
	Offer increased face-to-face discussion on process of converting a lab report to a Journal paper – the documentation is great, but it would still be helpful.
General Comments/ Suggestions	Two weeks into course, there was a major class roster re-shuffle which resulted in a significant number of new students who never heard the SRPP introductory session. I lost momentum after this.
	It's difficult to establish a culture of publishing when we don't even have an exemplar in the discipline and I've never been through the process.
	Although I was always excited about the *Journal*, with all the other responsibilities and demands, it frequently didn't get the time it deserved.
	Might be helpful to walk highly motivated kids through the process of turning a lab report into a Journal format even if their IRP has a flaw that precludes actual publication.

As noted previously, all involved now realize that the Trial Expansion was embarked upon with inadequate thought and study of the process. The author, upon reflection, fully recognizes that most of the issues identified above are a result of inadequate support and guidance on his own part, as the consultant for the implementing teachers. There was inadequate structure and guidance from the consultant regarding regular reminders and emphasis of the *Journal* and the SRPP throughout the course. There was inadequate support from the author/consultant in developing lists of research areas likely to yield publishable results to help guide students in topic selection. There was inadequate support from the author/consultant in developing exemplars for student reference, and there was inadequate support in screening and selecting IRP's for submission for review in the first few rounds. In sum, implementing the SRPP is not as easy as it seemed to the author in 2012.

One of the primary goals in the Trial Expansion of the SRPP into Biology and Chemistry was to learn about the process of implementing the SRPP in a new course through the experience of implementation. It must therefore be acknowledged that, as many flaws in the process were identified, this goal was met. Much was learned (even if only on how NOT to do it) during the Trial.

It is now time to turn to the second aspect of the study of the Trial Expansion: the results of the surveys administered to the students.

Effects of the Trial Expansion of the SRPP on student abilities and attitudes. The four surveys administered to the students in the Trial Expansion of the SRPP were the same as the surveys given to the students in the established SRPP for Objectives 1-3. The demographic variables collected were also the same as for Objectives 1-3. Therefore, the method of data analysis was the same as that used for the students in the established SRPP, which was described in detail in the first part of this chapter.

The method of preparing the data, checking for outside variables to be used as covariates, checking that assumptions required for the use of multivariate analysis of variance (MANCOVA) were satisfied, and running the MANCOVA and related procedures, were all identical to those described in the first part of this chapter, for Objectives 1-3. Therefore, in the interest of brevity, only the results of the analysis will be presented here.

Sample numbers and characteristics. Students enrolled in IB Biology and IB Chemistry at ISB in the classes of 2013-2014 were invited to participate in the study. Students in the IB HL Biology and IB HL Chemistry classes of 2014 were enrolled in the courses involved in the Trial Expansion of the SRPP. Students in the IB Biology and IB Chemistry classes of 2013, along with students enrolled in the IB SL Biology and IB SL Chemistry classes of 2014, were enrolled in standard IB courses that were not implementing the Trial Expansion as part of the course. The number of students in the populations of each of the groups, along with the number of students who consented to participate in the sample, is presented in Table 4.41. The total population was N = 186. The total sample from that was N = 144, which was greater than the N = 126 sample size needed to have a 95% confidence level in the results (Krejcie & Morgan). It must be noted that the sample for the Control Group, Students Not in Trial, was only at the 92.5% confidence level. Due to the fact that, in this study, existing populations of students enrolled in IB courses were used, neither the size of the populations nor the samples are equal.

Table 4.41: Population and Sample numbers by Trial Expansion participation status.

Status	Population N	Sample N	Percent of Pop. in Sample
In Trial	98	92	94
Not in Trial	88	52	59

The results of the four surveys investigating the effect of the Trial Expansion of the SRPP on students' science-related attitudes (TOSRA), understandings of the Nature of Science (SUSSI), and students' experimental research and publishing skills and attitudes (SSRSSA and AESP), will now be considered.

Effects of the Trial Expansion on students' science-related attitudes. The results of the preliminary analysis of students' responses to the Test of Science-Related Attitudes (TOSRA) instrument is presented in Table 4.42 on the following page. While the number of respondents not in the Trial Expansion (N = 50) was lower than the number that were in the Trial Expansion (N = 68), due to the characteristics and limitations of the available populations, it is quickly obvious that there is little difference between the two groups in all areas. All seven TOSRA factors, as well as the combined TOSRA score, show the mean response of students in the Trial Expansion to be little different from those not in the Trial Expansion. There is a small difference in Factor I: Attitude toward scientific inquiry, with those *not* in the Trial being slightly higher, as well as in Factor A: Adoption of Scientific Attitudes, with those *in* the Trial being higher. Given the results seen in Objective 1, and the finding that the SRPP does not have a significant effect on students' science-related attitudes in the established program in Physics, this is not surprising.

Table 4.42: TOSRA results from the two comparison groups, students **not** participating in the Trial Expansion of the SRPP and students participating in the Trial Expansion in IB Biology and Chemistry at ISB.

TOSRA Factor	Student Trial Status	N	Mean	SD	Percent Responses >= 4
Combined Score	Not in Trial	50	3.65	0.55	32
	In Trial	68	3.69	0.37	21
Factor S: Social Implications of Science	Not in Trial	50	4.01	0.37	64
	In Trial	68	4.12	0.43	66
Factor N: Normality of Scientists	Not in Trial	50	3.54	0.47	14
	In Trial	68	3.52	0.39	15
Factor I: Attitude to Scientific Inquiry	Not in Trial	50	3.57	0.77	30
	In Trial	68	3.28	0.73	22
Factor A: Adoption of Scientific Attitudes	Not in Trial	50	3.87	0.48	52
	In Trial	68	4.06	0.42	50
Factor E: Enjoyment of Science Lessons	Not in Trial	50	3.72	0.97	52
	In Trial	68	3.74	0.72	44
Factor L: Leisure Interest in Science	Not in Trial	50	3.12	0.99	28
	In Trial	68	3.35	0.70	22
Factor C: Career Interest in Science	Not in Trial	50	3.72	0.92	52
	In Trial	68	3.78	0.66	53

In order to determine the significance of the results, a MANCOVA was performed. The data analysis process of determining the necessity of a covariate and checking for the satisfaction of assumptions was identical to that used for the TOSRA in Objective 1. Looking at the results of the MANCOVA in Table 4.43, using Science and Math Coefficient as the covariate, we can see that this is confirmed. With one of the factors showing a small positive effect for those in the Trial Expansion and another showing a small negative effect, the overall combined score shows no significant difference.

Table 4.43: MANCOVA results showing significance of differences of TOSRA means, along with effect size, for students in the Trial Expansion of the SRPP, compared to those not in the Trial, controlling for the covariate 'Science and Math Coefficient'.

TOSRA Factor	Tests of Between-Subjects Effects		Effect Size ('In Trial' - 'Not in Trial')
	F	Sig.	
Combined Score	0.00	0.99	-
Factor S: Social Implications of Science	2.20	0.14	-
Factor N: Normality of Scientists	0.25	0.62	-
Factor I: Attitude to Scientific Inquiry	5.23	0.02*	-0.32
Factor A: Adoption of Scientific Attitudes	4.78	0.03*	+0.19
Factor E: Enjoyment of Science Lessons	0.32	0.57	-
Factor L: Leisure Interest in Science	1.07	0.30	-
Factor C: Career Interest in Science	0.02	0.88	-
* significant to the $p < 0.05$ level			

While it may be tempting to look for reasons for the significant differences in the two factors, it is quite likely that the reasons are unrelated to the Trial Expansion. It should also be noted that when many dependent variable comparisons are made, the occasional "false positive" is statistically likely, since a significant difference is defined as one with a less than 1/20 chance of being due to chance. While the Bonferroni adjustment attempts to account for this, there is still increased likelihood of false positives with increased numbers of dependent variables.

It has been shown, in general agreement with the findings of Objective 1, that there are no important differences in the science-related attitudes of students who participated in the Trial Expansion of the SRPP into Biology and Chemistry compared to those who did not. While there were significant differences ($p < 0.5$) in two factors, it is suggested it is likely that these do not represent important effects of Trial Expansion participation.

Effects of the SRPP on understanding of the nature of science. The second aspect of the effects of the SRPP to be examined is its effects on student understanding of the Nature of Science (NOS), as measured by the Student Understanding of Science and Scientific Inquiry, (SUSSI). This was the instrument used in Objective 2, which was been previously described. The results of the preliminary analysis of the student responses to the survey are presented in Table 4.44.

Table 4.44: SUSSI results from the two comparison groups, students **not** participating in the Trial Expansion of the SRPP and students participating in the Trial Expansion in IB Biology and Chemistry at ISB.

SUSSI Factor	Student Trial Status	N	Mean	SD	Percent Responses >= 4
Combined Score	Not in Trial	39	3.52	0.32	8
	In Trial	65	3.51	0.40	9
Factor 1. Observations and Inferences	Not in Trial	39	3.85	0.61	59
	In Trial	65	3.62	0.79	42
Factor 2. Change of Scientific Theories	Not in Trial	39	4.02	0.48	69
	In Trial	65	4.04	0.71	68
Factor 3. Scientific Laws vs. Theories	Not in Trial	39	2.83	0.50	0
	In Trial	65	2.81	0.47	3
Factor 4. Social and Cultural Influence on Science	Not in Trial	39	3.63	0.61	44
	In Trial	65	3.71	0.68	55
Factor 5. Imagination and Creativity in Scientific Investigations	Not in Trial	39	2.97	0.78	13
	In Trial	65	3.06	0.93	26
Factor 6. Methodology of Scientific Investigation	Not in Trial	39	3.84	0.49	44
	In Trial	65	3.80	0.44	42

Looking at the results, it can be seen that the means of those participating in the Trial and those not participating in the Trial are very close to the same. This is similar to the SUSSI results in Objective 2, which compared those in the established Physics SRPP to those not in the SRPP. Again, this is not surprising, as the conclusion was that the established SRPP has no significant effects on student understanding of the Nature of Science. The SRPP does not explicitly instruct students in aspects of the Nature of Science, and it has been shown that direct instruction is necessary to change student understanding of NOS (Abd-El-Khalick, 2001).

It can also be seen that the level of understanding of the various NOS aspects of the Biology and Chemistry students here is very similar to the Physics students surveyed in Objective 2. Factor 2, Change of Scientific Theories, shows high levels of informed views. Factor 3, Scientific Laws vs Theories, shows very low levels of informed views. And the rest of the aspects of NOS show medium levels of students with informed views. Looking at Table 4.12, it is seen that these results are similar to the Physics students' levels of understanding of NOS.

In the interest of confirming the lack of significant differences in NOS understanding between students participating in the Trial Expansion and those not participating, the MANCOVA results are presented in Table 4.45. The data analysis process of determining the necessity of a covariate and checking for the satisfaction of assumptions was identical to that used for the SUSSI in Objective 2.

It is immediately clear that there are no significant differences in student understanding of NOS, as measured by the SUSSI instrument, between Biology and Chemistry students who did participate in the Trial Expansion of the SRPP and those who did not. This is not unexpected, as the established SRPP in Physics also was shown to have no significant effects on students' understanding of NOS.

Table 4.45: MANCOVA results showing significance of differences of SUSSI means, along with effect size, for students in the Trial Expansion of the SRPP, compared to those not in the Trial, controlling for the covariate 'Science and Math Coefficient'.

SUSSI Factor	Tests of Between-Subjects Effects		Effect Size ('In Trial' - 'Not in Trial')
	F	Sig.	
Combined Score	0.05	0.82	-
Factor 1. Observations and Inferences	2.03	0.16	-
Factor 2. Change of Scientific Theories	0.12	0.73	-
Factor 3. Scientific Laws vs. Theories	0.31	0.58	-
Factor 4. Social and Cultural Influence on Science	0.15	0.70	-
Factor 5. Imagination and Creativity in Scientific Investigations	0.17	0.68	-
Factor 6. Methodology of Scientific Investigation	0.02	0.90	-

Effects of the Trial Expansion of the SRPP on students' research and publishing skills and attitudes. Having looked at the effects of the SRPP on student science-related attitudes and on student understanding of the Nature of Science, it is time to look at the effects of the program on students' research skills and attitudes. The primary tool used to do this was the Secondary Science Research Student Self-Assessment (SSRSSA). Remembering from Objective 3, it was found that there were very significant differences between students in the established SRPP and those not in the SRPP in Physics for all factors of this instrument, with the students in the SRPP being stronger in all aspects. It was also shown that nearly all items in every factor showed significantly higher means for students in the SRPP.

It was concluded that these results were a valid effect of the SRPP (rather than a correlation caused by an outside factor) as the SRPP directly addresses the authenticity of the scientific discovery process experienced by students, focusing them on using the scientific process to create new knowledge within the context of current knowledge, and offering them the possibility of becoming part of the scientific community through publishing their findings in an entry-level Journal.

It will now be determined whether the students in the Trial Expansion of the SRPP into Biology and Chemistry, with all its flaws (noted in the previous section), experienced the same clearly significant effects as the students in the established SRPP in Physics.

Effects of the research aspect of the SRPP on students. The results of the SSRSSA responses by students who did and did not participate in the Trial Expansion of the SRPP are presented in Table 4.46 on the following page. Upon examining the data in Table 4.46, it is immediately obvious that there is little difference in means between the groups. This is a very different result from the students in the established SRPP in Physics, where there was an obvious positive effect for all SSRSSA factors. Clearly, for whatever reason, participation in the Trial Expansion of the SRPP had no effect on students' experimental research skills and attitudes.

Table 4.46: SSRSSA results from the two comparison groups, students **not** participating in the Trial Expansion of the SRPP and students participating in the Trial Expansion in IB Biology and Chemistry at ISB.

SSRSSA Factor	Student Trial Status	N	Mean	SD	Percent Responses >= 4
Combined SSRSSA Score	Not in Trial	40	3.43	0.57	13
	In Trial	92	3.45	0.55	17
SSRSSA Factor 1. Thinking and Working Like a Scientist	Not in Trial	40	4.06	0.51	65
	In Trial	92	4.02	0.64	70
SSRSSA Factor 2. Personal Gains	Not in Trial	40	3.74	0.77	50
	In Trial	92	3.76	0.62	45
SSRSSA Factor 3. Skills	Not in Trial	40	3.60	0.61	30
	In Trial	92	3.57	0.63	28
SSRSSA Factor 4. Attitudes and Behaviors	Not in Trial	40	3.03	0.92	20
	In Trial	92	3.15	0.80	17
SSRSSA Factor 5. Experience in Science Class[a]	Not in Trial	40	2.77	0.53	38
	In Trial	92	2.87	0.51	53
a Percent responses >= 3. (Scale for factor 5 was 1-4)					

In the interest of completeness and confirmation, the MANCOVA was performed with the Science and Math Coefficient as the covariate. The data analysis process of determining the necessity of a covariate and checking for the satisfaction of assumptions was identical to that used in for the SSRSSA in Objective 3. The results are presented in Table 4.47 below.

These results do confirm the observations based on the means of the two groups presented in Table 4.46. There are no significant differences between means of the groups for any of the factors measured by the SSRSSA instrument. Participation in the Trial Expansion of the SRPP had no effect on any of these factors of students' experimental skills and attitudes. In order to parallel the analysis performed in Part 1, an item analysis was performed for each of the five factors. It showed that there were no differences in any of the 43 items in the five factors, except

Table 4.47: MANCOVA results showing significance of differences of SSRSSA means, along with effect size, for students in the Trial Expansion of the SRPP, compared to those not in the Trial, controlling for the covariate Science and Math Coefficient.

SSRSSA Factor	Tests of Between-Subjects Effects		Effect Size ('In Trial' - 'Not in Trial')
	F	Sig.	
Combined SSRSSA Score	0.03	0.87	-
SSRSSA Factor 1. Thinking and Working Like a Scientist	0.20	0.66	-
SSRSSA Factor 2. Personal Gains	0.21	0.65	-
SSRSSA Factor 3. Skills	0.04	0.84	-
SSRSSA Factor 4. Attitudes and Behaviors	0.04	0.85	-
SSRSSA Factor 5. Experience in Science Class	0.47	0.50	-

for two items, with one of the items showing participating students higher and the other lower. As previously explained, a few 'false positives' are to be expected, statistically, when looking at many dependent variables, even when employing the Bonferroni adjustment. It will thus be assumed that no conclusions can be drawn from the difference of these two items.

Effects of the publishing aspect of the SRPP on students. And, finally, to the fourth survey instrument: the Attitudes toward and Effects of Student Publishing. Remembering from Objective 3, the AESP was designed to investigate the effect of the *Journal* and the possibility of publishing on student abilities and attitudes. Thus it was only administered to students who participated in the Trial Expansion, not to students who did not. Section 3 of the instrument, which was targeted at students who had published papers in the *JoS*, was not administered to students in the Trial Expansion group, as they did not meet these criteria.

As there can be no comparison of the results of this instrument with students who did not participate in the Trial Expansion, and the results in isolation mean little, it was decided to compare the results of the AESP administered to the Trial Expansion group with those of the established SRPP group presented in Objective 3 of this chapter.

The results of AESP section one, which queried students' level of interest in publishing, was a mean of 2.2 for students in the Trial Expansion, or slightly above the second choice of 'a little interested'. Only 16% of respondents chose 'very' or 'extremely' interested. This is in contrast to the students in the established SRPP which had a mean of 3.0, corresponding to the third choice of 'interested', with 33% of respondents choosing the "very" or "extremely" interested. This is a very significant difference, with the t-test for equality of means returning a p-value of 0.000.

Continuing to Section 2 of the AESP instrument, the means of the seven items for the two groups are presented in Table 4.48 on the following page. It is immediately obvious that the means for the established SRPP students is higher than those of the Trial Expansion students for all items.

Table 4.48: AESP results from the two comparison groups, students participating in the Trial Expansion in IB Biology and Chemistry, and students participating in the established SRPP in Physics.

Section 2: To what extent did the possibility of publishing affect…	SRPP Status	N	Mean	SD	Percent Responses >= 3
2.1- ….your effort in choosing a research question for your IRP's?	Trial Expansion (Bio & Chem)	81	2.05	1.05	35
	Established Program (Physics)	95	2.44	1.01	51
2.2- ... your effort in finding and understanding background theory for your IRP's?	Trial Expansion (Bio & Chem)	81	2.07	0.97	36
	Established Program (Physics)	96	2.40	1.02	50
2.3- ... your effort in designing your experimental setups and methods for your IRP's?	Trial Expansion (Bio & Chem)	81	1.99	0.97	28
	Established Program (Physics)	96	2.39	1.06	43
2.4- ... your level of care and attention to detail when conducting for your IRP's?	Trial Expansion (Bio & Chem)	81	2.23	1.13	43
	Established Program (Physics)	95	2.68	1.06	62
2.5- …your willingness to spend extra time outside of class to ensure valid results for your IRP's?	Trial Expansion (Bio & Chem)	80	1.99	1.09	33
	Established Program (Physics)	95	2.60	1.04	59
2.6- ... your effort in the processing and analysis of data for your IRP's?	Trial Expansion (Bio & Chem)	80	2.15	1.08	25
	Established Program (Physics)	95	2.59	1.12	58
2.7- …your effort in writing the report for your IRP's?	Trial Expansion (Bio & Chem)	80	2.19	1.10	39
	Established Program (Physics)	96	2.55	1.08	58

After the established data processing and analysis, the MANCOVA, shown in Table 4.49 below, confirms this. The data analysis process of determining the necessity of a covariate and checking for the satisfaction of assumptions for MANCOVA was identical to that used in for the AESP previously.

Table 4.49: MANCOVA results showing significance of differences of AESP Section 2 item means, along with effect size, for students in the Trial Expansion of the SRPP, compared to those established SRPP, controlling for the covariate 'Science and Math Coefficient'.

Section 2: To what extent did the possibility of publishing affect…	**Tests of Between-Subjects Effects**		**Effect Size ('Established' - 'Trial')**
	F	**Sig.**	
2.1- ….your effort in choosing a research question for your IRP's?	5.70	0.018*	+0.38
2.2- ... your effort in finding and understanding background theory for your IRP's?	4.56	0.034*	+0.33
2.3- ... your effort in designing your experimental setups and methods for your IRP's?	6.14	0.014*	+0.38
2.4- ... your level of care and attention to detail when conducting for your IRP's?	5.58	0.019*	+0.39
2.5- …your willingness to spend extra time outside of class to ensure valid results for your IRP's?	13.35	0.000**	+0.58
2.6- ... your effort in the processing and analysis of data for your IRP's?	6.37	0.013*	+0.42
2.7- …your effort in writing the report for your IRP's?	4.45	0.036*	+0.35
* significant to the p < 0.05 level ** significant to the p < 0.01 level *** significant to the p < 0.001 level			

Clearly, the results of the MANCOVA confirm our suspicions: the possibility of publishing had significantly less effect on the students' levels of effort in all areas of experimental research queried for students in the Trial Expansion when compared to students in the established SRPP.

It has been shown that there were no differences between those participating in the Trial Expansion of the SRPP in Biology and Chemistry and those not participating for the first three of the instruments used, designed to measure science-related attitudes, understanding of NOS, and Skills and Attitudes toward experimental research. While no differences were expected for the first two areas, the lack of difference for the third area was unexpected. It has been further shown that student responses on the AESP instrument, designed to measure the effect of the possibility of publishing in the *JoS* on student effort in experimental research, was significantly lower for students in the Trial Expansion than for students in the established SRPP.

Clearly, the effects of the SRPP, detected by the SSRSSA and the AESP, that were so strongly evident in the students of the established SRPP in Objective 3, were not replicated in the Trial Expansion of the SRPP into Biology and Chemistry. The reasons for this can begin to be seen in the Trial Expansion Teacher Interview, discussed earlier. Further understanding of this result can be obtained by looking at the responses to the open-ended items in the SSRSSA and AESP instruments. The responses to these open-ended items by the participants in the Trial Expansion were analyzed in the same way as was done in Objective 3 earlier in this chapter. The results indicate two main categories of responses that explain the lack of difference between those who did participate in the Trial Expansion and those who did not.

The first category is responses that indicate a lack of confidence in the student's ability to do work worthy of publishing in an entry-level Journal. The following responses illustrate this. These responses were selected from academically strong students, as those students where shown in Objective 3 to be most interested and most likely to publish, given the opportunity.

> "Although it would have been nice to have a published piece, none of my work was original enough and I didn't want to spend the time re-writing my reports to fit the published criteria."

> "I honestly knew that although the opportunity was there, my work would never be good enough for the *Journal of Science*. The notion made the possibility of being published not something that I was striving for."

> "I felt like I couldn't achieve something like that anyways, so I really just didn't bother."

> "To have been published even while still in high school was unthinkable for me."

These attitudes explain the dearth of work submitted for consideration for publishing. It is suggested that this may be attributed to two factors noted in the Trial Expansion Teacher Interview: Lack of provision of exemplars of previous student work of a publishable standard and lack of provision of a list of research areas likely to yield publishable results. Without strong encouragement and support, students in secondary school are likely to lack the motivation and confidence to pursue this challenge.

The second category identified in the analysis of the open-ended responses was lack of awareness of, or understanding of, the opportunity to publish in the *JoS*. This response was very common among those who had expressed strong interest in publishing in section 1. Again, the responses of academically strong students have been selected.

> "Frankly, I never once thought about the *Journal of Science* while I did my IRPs. My teacher mentioned it once at the beginning of the semester and that was it. It did not affect the effort I put into my IRPs nor did it affect my attitudes toward science and research."

> "Wait, is there a reason why the *Journal of Science* only has physics experiments in it? Are chemistry and biology students denied the opportunity or has word not yet spread of its existence? I would think my views would have changed if I were given the opportunity and guidance to strive for a publication."

> "I did not learn about the ISB *Journal of Science* until the second semester of chemistry. I still do not know all of the requirements needed to publish a paper in the *ISB Journal of Science*."

> "Even though I may have been excited to be able to publish a paper, I was rarely thinking about the opportunity while conducting research because, after our introduction, we never talk (sic) about how to get your paper published or what the requirements were in order to get your paper into the

> *Journal*. Essentially, there was not much emphasis put on it, and it was always just at the back of my mind."
>
> "It was never fully explained to me what exactly is the *ISB Journal of Science.* I just thought it was a collection of really well done IRPs that past students have done."
>
> "It was never really mentioned in either of my science classes except as a very brief one sentence idea that was introduced early in the year and never touched upon again. I was never made aware as to the process behind getting a paper to even be reviewed or what the criteria were to be included in the paper or anything that would have helped me work towards getting a research paper in the *Journal*."
>
> "I didn't know we had a *Journal of Science*."

While there is a little hyperbole in some of the student reactions, the message is clear. The SRPP was not emphasized clearly and regularly enough. The implementing teachers did thoroughly introduce the *Journal* and the SRPP program in the first days of the course, but students at the beginning of the IB Diploma program are often scared, stressed, and overwhelmed. Introductory lectures under those conditions are often not well internalized. The criteria for publishing, exemplars of publishable work, and explanation of the publishing process must be repeatedly presented to students. Then, students must be encouraged repeatedly to consider the challenge, and provided with support in choosing areas for research. This message matches the feedback from the implementing teacher in the previous section. There was clear teacher awareness that the SRPP had not been emphasized regularly enough or strongly enough to allow it to affect student attitudes and behaviors, hence student outcomes. The teacher also pointed to a need for more support for students in choosing research areas for their IRP's.

Summary: Findings from the Trial Expansion of the SRPP. Both the teachers and the students identified two main areas in which the Trial Expansion was poorly implemented. Firstly, while the SRPP introductory session at the beginning of the course was well done, there was not enough regular emphasis or reminders integrated throughout the course. This led to students forgetting about the opportunity, or failing to be convinced of their ability to rise to the challenge.

Secondly, there was a lack of prepared supporting resources to aid students in accepting the challenge of aiming to publish and in choosing appropriate areas for research. Two resources were identified as being useful: An archive of exemplars of student work appropriate for publishing in an entry-level Journal, and a list of areas of research likely to yield publishable results. While these resources are available for students in the established SRPP in Physics, these resources are subject-specific and should have been developed for Biology and Chemistry prior to the implementation of the Trial Expansion. The inadequacy of the Trial Expansion process in these two areas led to the lack of papers published by students in the Trial Expansion courses. It also led to a lack of effect on students' research skills and attitudes, which was shown so strongly among the students in the established SRPP.

Finally, the number of papers published by students participating in the trial expansion was less than had been hoped for. In Chemistry, one IRP was submitted to the reviewer for consideration. However, the reviewer rejected that paper. In Biology, two papers were considered for publication, with only one being accepted by the reviewer for publication. So for the roughly 90 students in the trial expansion, one paper was published. In comparison, the most recent group of 40 students in the established SRPP in Physics published a total of five papers.

The findings from this component of the study for Objective 5 have shown that implementation is much more difficult than originally thought. A number of flaws were identified in the process of implementation of the Trial Expansion, with the flawed implementation leading to no significant effects of the Trial Expansion process on student outcomes.

Building the Model for Implementation of the SRPP

Having learned lessons from the Trial Expansion of the SRPP into Biology and Chemistry, the next step in the development of a Model for Implementation of the SRPP was to gather information from experts and others with familiarity with, or direct experience of, the SRPP. This enabled the creation of a draft of the Model for Implementation. While the details of the methods for this part are provided in the previous chapter, a summary will be provided here as a reminder.

Interviews. The information was gathered through the use of a semi-structured interview instrument, lasting about an hour, administered to both educational experts and student SRPP participants. The eight educational experts interviewed included the co-founder of the *Journal of Science*, four teachers (two who participated in the Trial Expansion and two familiar with the SRPP, but who had never taught a course implementing the SRPP), and three administrators familiar with the SRPP. The six student SRPP participants interviewed had all studied in the established SRPP program in IB Physics, with three of the six having published a paper, and two of the six, being graduates, interviewed by Skype while at university. The fact that the author is a colleague of all the adult interviewees, and the teacher of the student interviewees, led to concern that interviewees might be reluctant to criticize or realistically evaluate the SRPP during the interview. An unknown, outside interviewer was therefore asked to conduct the interviews.

Three versions of the interview protocol were developed for the three unique groups of interviewees: 1. Students who have published, 2. Students who have not published, and 3. Teachers and Administrators. The three versions had a common core of six questions, with a range of other questions, designed to match the characteristics of each group, included in the three versions. The three interview protocols, shown in Appendix F, elicited interviewees' views on the benefits and costs of the SRPP, and the processes and challenges of how it might be implemented in a new school.

Interview analysis. After the interviews were conducted, they were transcribed in full, yielding over 100 pages of text. An inductive thematic analysis (Braun & Clark, 2006) of the transcripts was performed to identify key findings and important themes. The analysis was organized by interview question, with a total of 17 unique and shared questions in the three interviews. The results, shown in Appendix G, are presented as a series of tables, one for each interview question, summarizing unique aspects of each interviewee's relevant responses, with summary key findings and themes at the top of each column.

Finally, the results of the analysis of each question were combined into a single table summarizing the key findings and important themes voiced by the interviewees. This is shown in Table 4.50 on the following page. The responses (codes) were grouped into a number of themes (topics or phrases).

Table 4.50: Summary of the results of the thematic analysis of the Model for Implementation interviews.

Topic	Key Finding or Theme
Value of SRPP	Skills developed: Hands-on problem solving, applying theory, gaining in-depth understanding, improved writing, data-analysis & evaluation skills, creativity, independence, time management and organization, think like a scientist.
	Other Benefits: helps at university, motivates interest in science, sense of fulfillment, feel part of scientific community. Authentic science engaging learners. Challenges all students to push themselves, encourages rigor. Publishing complements the IRP program, and is optional.
	"If you are passionate about your discipline, about the experimental sciences, and if you're passionate about education, this affords you opportunities, real connections, real possibilities for your students that you don't have otherwise."
Require-ments for successful implemen-tation	Students: intrinsic motivation, enjoy challenging themselves. don't need to be most academically gifted, but minimum level of ability and motivation needed
	Teachers: Competent, strong in inquiry teaching, knowledgeable in subject. Understand process of scientific research. Passionate about program
	Admin: Supportive/see value of program. No need for direct involvement.
	Curriculum: Requires both lab work & content. Well-implemented IRP program. Scaffolded series of labs to teach skills of open inquiry leading up to IRPs.
	Labs and Equipment: Standard labs and equipment of developed country HS is adequate for the SRPP program. Must have computers and data-collection probes. Variety of equipment, ability to source on short notice.
	Enthusiastic teacher with flexibility to get it started. Students with motivation and interest. School and curriculum need to be flexible, to allow teachers the freedom to innovate with independence, creativity. Adequate resources
	Determine if school has the capacity and need for program. Valuable program, but must have right environment and conditions, not suited for every school.
Preparation for Implemen-tation	Teachers: Training for the skill set involved in the program. Long-term expert consultant to guide the process. An exemplar modeling the program
	Admin: Pick staff that have the capacity, passion, then give them freedom to operate. Support the program with resources. Support implementing teachers. Ensure a clear understanding of program by teachers, students, and parents
	Establishing Journal: External reviewer who is knowledgeable and respected. Exemplar/ training in how to establish Journal and write papers
	Students and Parents: Present program and its advantages to students and parents. Present individually to students you judge are capable and interested. Don't need much publicity to parents/community.
Initial Implemen-tation	One teacher, one subject, start quietly, then expand later. If have failures, can just pick yourself up, learn from the failures, and try again.
	If have teachers interested from all subjects, go ahead and start all at once.
Implemen-tation Timeline	If established Inquiry program, then min 2 years to establish the publishing aspect. 1 year to get things organized. 1 year to get students involved, work out procedures. Starting from 3rd year, looking to publish first papers. Could be longer depending on school culture.

Draft Model development and validation. Using the key findings and themes from the interview analysis as the foundational structure, a draft of the Model for Implementation of the Student Research and Publishing in Secondary School Science was developed, revised, and prepared for expert validation. The draft of the Model for Implementation, including the expert validation form used, is presented in Appendix H.1.

The draft Model for Implementation was sent to a total of 18 experts for validation and was returned by 16 of them. Of these, three were outside educational experts, not familiar with the SRPP, holding PhD's, with a wide range of experience in science education, educational leadership, and educational development and reform. One of the validators was an expert teacher of English as an Additional Language (EAL). The rest of the validators were those who had participated in the initial interviews, with the *JoS* co-founder, three administrators, three science teachers, and five students returning validation forms.

The Model was approved by all validators. An example of one of the returned Validation forms is shown in Appendix H.2. The Model received an average rating from the validators of between 'Agree' and 'Strongly Agree' for the Model's Precision, Sufficiency, Feasibility, and Effectiveness. Most validators also offered comments with suggestions for improvements. A summary of the validator's ratings and comments is provided in Appendix H.3

Model revision and finalization. The draft Model was revised, extended, and improved, based on the feedback and recommendations of the validators. The resulting Model for Implementation of a Student Research and Publishing Program in Secondary School Science is presented in the following section.

Results

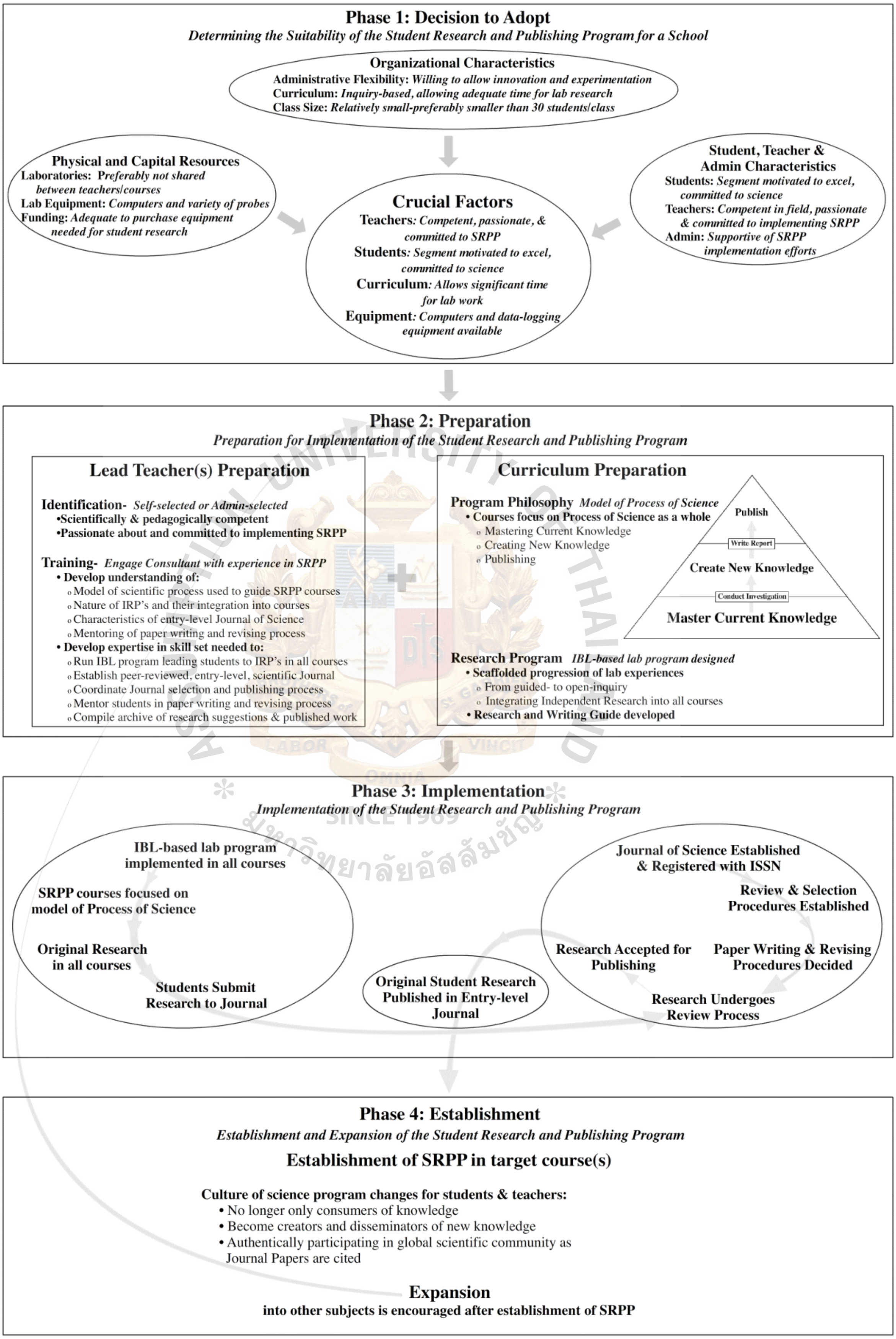
Objective 5: Development of a Model for Implementation of a Student Research and Publishing Program in Secondary School Science.

Model for Implementation of a Student Research and Publishing Program in Secondary School Science

The Student Research and Publishing Program in Secondary School Science has been shown to yield positive results over a range of student research and publishing abilities and attitudes. It is expected that schools that are made aware of this program may be interested in implementing it. The following is a Model that can be followed by secondary schools during implementation of a Student Research and Publishing Program in science. Using this Model for Implementation at a school is expected to result in a successfully established Student Research and Publishing Program at that school. A successfully established Program is defined as having the characteristics and outcomes of the currently established SRPP described in detail in Chapters 1 and 3. This includes using the simplified SRPP model of the Process of Science as a focusing structure for the course. It also includes having Independent Research Projects (IRP's), where students conduct authentic, original experimental research, integrated into all courses participating in the Program, as well as Journal papers being published regularly. A successful SRPP will have student outcomes similar to those described in the first four objectives addressed in this chapter.

A visual representation of the Model for Implementation is shown in Figure 4.1. This is followed by a detailed description of the Model.

Figure 4.1: The Model for Implementation of the SRPP.



Phase 1: Decision to Adopt - ***Determining the Suitability of the Student Research and Publishing Program for a School***

The first step in the implementation process is to verify the suitability of the SRPP for a particular school. It is clear that this program is not suitable for all schools and that not all schools have the capacity to successfully implement it. It is thus necessary for a school to conduct a study to determine whether the SRPP could be successfully implemented.

Organizational Characteristics. The following are the characteristics of a school that is likely to benefit from the SRPP and at which implementation has a higher chance of success.

Administrative Flexibility. The administrative structure of the school must be quite flexible. Schools that allow teachers and students the freedom to experiment and innovate are more likely to succeed. Schools which are rigid in the curricular and program requirements, which have tightly prescribed programs, and at which new programs require approval from many levels of the organization are unlikely to succeed in, or benefit from, implementation of the SRPP.

Curriculum. The curriculum at the school must be one that allows for significant time to be devoted to lab work. The science program must have inquiry-based learning fully integrated into the curriculum, with course experiences progressing from guided-inquiry through to open-inquiry. Open-inquiry must be a regular feature of the secondary science courses at the school.

Class Size. Class sizes at the school must be small enough so that teachers have the time to institute Independent Research Projects as part of the curricular program. In a class of 40 students it would be impossible to run IRP's, and the time required to grade the reports would be untenable for the teacher. Class sizes of 25 or less are recommended for successful implementation of the SRPP.

Physical and Capital Resources.

Laboratories. While having one lab for each teacher is an advantage, the SRPP can be implemented in schools where teachers share lab rooms.

Lab Equipment. Any school that has science labs furnished to a standard typical of schools in developed countries, with computers and peripherals for data collection, is capable of implementing the SRPP. The ability to source a variety of non-typical equipment on short notice is an advantage, as that allows students to follow their interests when conducting Independent Research Projects.

Funding. The school must have the funding to support the SRPP. While not excessive, funding is needed for the purchase of a variety of equipment for IRP's. Funding for teacher stipends may also be considered.

Student, Teacher and Administrator Characteristics.

Students. There must be a significant proportion of students at the school who value education and are interested in pursuing science as a career. It is not necessary to be a selective school with gifted students. Students who are motivated to excel and are committed to science are all that is needed to be able to implement a successful SRPP.

Teachers. The school must have one or more teachers who are well-trained in their disciplines. They must be skilled in teaching open-inquiry in science and familiar with the process of scientific research. They must be passionate about teaching science, able to inspire and engage their students. Finally, and it must be emphasized that this point is crucial, the teacher(s) selected to implement the program must be passionate about, and strongly committed to, implementing the Student Research and Publishing Program. If these key criteria are not met, it is not expected that a school will be successful in implementing the program.

Administrators. Administrators at the school should understand the SRPP and see the value in it, commit adequate resources to supporting it, and, if necessary, work to clear any institutional roadblocks to implementing the program. Given that the SRPP is primarily teacher-driven, there is little requirement for direct administrator action beyond this.

A summary of the factors to be considered in determining the suitability of a school for implementation of the SRPP is shown in Table 4.51, with an estimation of its relative importance in determining the success of the program.

If conditions at the school are in reasonably close alignment with those outlined above, it can be concluded that the Student Research and Publishing Program would be highly beneficial to the students and its implementation stands a high chance of success. It must be emphasized that the lack of any factor rated crucial in Table 4.51 is expected to lead to failure in the implementation of the SRPP, and implementation is not recommended.

Phase 2: Preparation - *Preparation for Implementation of the Student Research and Publishing Program*

Note: For this part of the Model, it will be assumed that the school meets all the crucial criteria outlined in Phase 1. If a school is lacking in any specific area, it is recommended that the issue be addressed **before** implementation of the

SRPP. The details of the remediation process needed in any particular area are beyond the scope of this Model and will not be addressed here.

Table 4.51: Factors to be considered in the implementation of the SRPP.

Level of Importance	Factor
Crucial	Lead teacher who is competent, passionate about, and committed to the SRPP
	Segment of students motivated to excel and committed to science
	Curriculum that allows significant time for lab work
	Computers and data-logging equipment available
Important	Administrative flexibility
	Small class sizes
	Funding to support program
Helpful	Administrators committed to the program
	Well-equipped labs
	Dedicated labs
	Ability to quickly source non-typical equipment

The preparation necessary for implementation of the SRPP varies with the school. Each school will find itself in a unique situation, so each school will have a unique path to implementation of the SRPP. However, certain general areas of preparation can be identified.

Identifying the lead teacher(s) for implementation of the SRPP. This can occur in one of two ways. If the administration of the school is the driving force behind implementation, they need to approach a teacher or group of teachers that meet the criteria with a proposal to implement the SRPP and obtain their commitment to the program. This commitment may take some time to obtain, depending on the school and the teachers. It is also possible for implementation of the SRPP at a school to be teacher-driven. In this case one or more teachers will see the value of the SRPP and commit to implementing the program. They would need to approach the administration to obtain their commitment to support the program as necessary.

This is probably the most difficult step in the whole process. Given that the drivers of this program are teachers, it is impossible to implement without the leadership of a teacher who is scientifically and pedagogically competent, and is passionate about, and committed to, establishing the SRPP at the school. This point cannot be emphasized strongly enough.

Training the lead teacher(s). Implementation of the SRPP will be most efficient and have the highest chance of success if a consultant with experience in running a successful program is engaged to train the lead teacher(s).

The details of how the training is conducted are highly dependent on the circumstances of both the lead teacher and the consultant. The training may take the form of a short initial workshop, followed by continued support via electronic communication. If the consultant or a school with an established SRPP is close to the implementing school, it may be more effective to have a series of exchange visits over the course of implementation.

Whatever the form of the training, the consultant will need to ensure that the lead teacher(s):

- Understand the benefits of the program, including expected student outcomes and long-term changes in school culture.
- Develop an in-depth understanding of the details of the program, including:
    - the nature of the scientific model used to guide teacher and student thinking,

    - the nature of IRP's and how they are integrated into the courses,
    - the establishment of the Journal and the criteria for selection,
    - and the paper writing and revising process

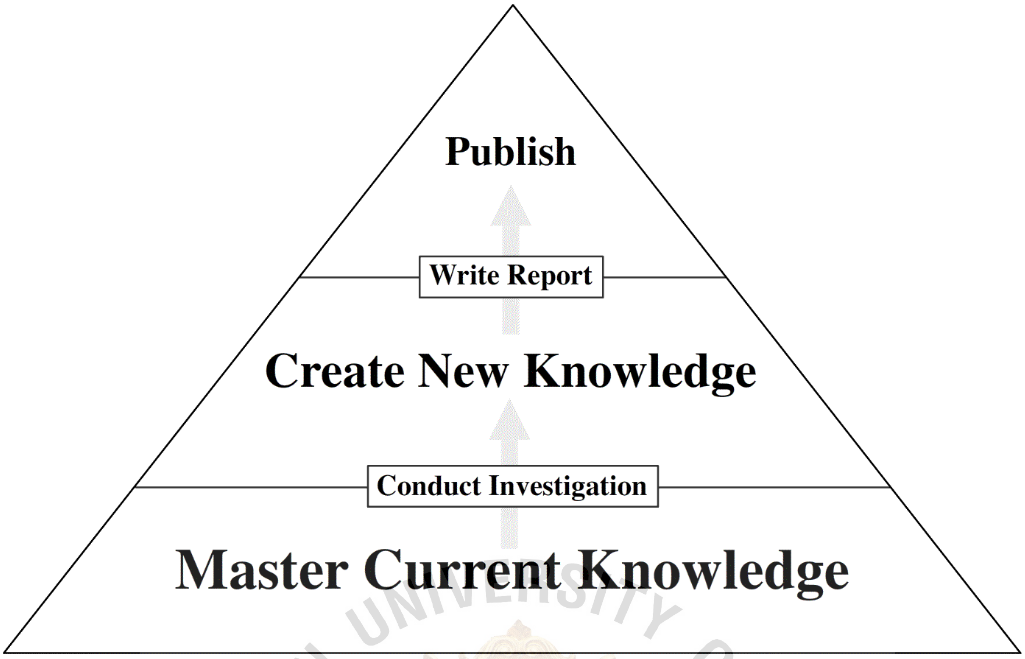
- Develop expertise in the skill set needed to implement and run the program, including:
    - using a scaffolded series of lab investigations, from guided-inquiry to open-inquiry, to prepare students for IRP's,
    - running an IRP program in each course,
    - coordinating the Journal selection and publishing process
    - mentoring students in the process of writing and revising a paper.
    - compiling an archive of exemplars and published work at the appropriate level, along with suggestions for general topics likely to be suitable for the level of the students and the equipment available.

The use of an established program as an exemplar of all the components and processes involved in the SRPP would be beneficial in this process. The lead teacher(s) could study all aspects of that program as part of the training process.

Preparing the curricular research program. It is essential that the philosophy and organization of the science program be aligned with the SRPP. Each course must be (re-) designed to focus not only on content mastery, but on the process of science as a whole. It is recommended that a simplified model of the scientific process, like that shown in Figure 4.1, be used to help students understand.

Students must be reminded regularly that the mastery of the course content is the foundation for the knowledge creation and publishing processes. Mastering content for the sake of the content is not enough. New knowledge must be created and then published to add to the current knowledge.

Figure 4.2: The simplified SRPP model of the scientific process.



The lab component of each course must prepare the student for the culminating Independent Research Project, in which students design and conduct original research within the context of the course content to create new knowledge, with the view to potentially publishing their results. The need for this (re-) design step will depend on the school, with some schools having Independent Research programs already established only needing minor tweaks while schools without a well-established IRP program will need more significant modifications to their programs.

It is also recommended that a resource be developed that guides students in how to design, conduct, and report on IRP's. This 'Research Guide' describes best-practice in designing and conducting IRP's, and gives detailed guidelines on the requirements for writing the report for the IRP. This resource should be available to all students and referred to regularly by the teacher to help students as they plan and conduct their research and report their findings.

Establishing appropriate teacher compensation and student recognition. A system offering compensation of some form for the teachers involved, whether it be financial or time-based, should be established in preparation for implementation of the SRPP. It is recommended that recognition of achievement protocols for students who publish their work be considered. The ways in which students are recognized will vary according to the school, but may take the form of recognition at assemblies or in school publications, or the issuing of certificates of achievement.

Phase 3: Implementation - *Implementation of the Student Research and Publishing Program*

Once the lead teacher(s) have been identified and trained, and the curricular research program has been designed, it is time to begin implementation of the Student Research and Publishing Program.

Research. Implementation of the SRPP should start with implementation of the in-course research part of the program, if it is not already well established. Courses must be implemented, starting with the first year in the upper secondary school, which have an IRP incorporated into them. Students in all courses need to be regularly reminded of the philosophy of the program, with its emphasis on the scientific process, and the IRP's focus on knowledge creation with a view to potentially publishing a paper. It must be emphasized in the program that publishing work depends on the results of the research, and not on the desire of the student to publish. The level of difficulty of this step is very much dependent on the situation in the school. As noted above, schools with well-established IRP programs will need to spend little time on this step, while other schools might need to expend significant effort.

Publishing. After the research aspect of the program has been established in the science program for a year or more, it is expected that some students will begin to produce work that is worthy of consideration for publishing. Now is the time to establish the capacity to publish student work. In order to do this the *Journal of Science* must be established, then the publishing process must be established and teachers trained.

Establishing the Journal of Science. An online Journal requires a website. Whether this is designed and managed by the lead teacher or by a member of the tech department is unimportant. It is important that the Journal be registered with the ISSN center in the country of publication. This establishes legitimacy and allows other scientists and journal indexing sites to recognize the Journal as a legitimately published academic journal.

Selecting and training Reviewers. An important aspect of the current scientific publishing process is the review process. Having submitted papers reviewed and approved anonymously by outside experts is how the scientific community ensures the validity of published work. It is crucial that knowledgeable and respected reviewers be selected to participate in the program. Either the lead teacher or the consultant must then train the reviewers in their role. The training should brief the reviewers on the publishing guidelines, the process of reviewing the original submitted work, and then reviewing and approving the final paper. Reviewers may be current or former teachers, or experts in the field with links to the school. Reviewers must not know the identity of the students whose work they are reviewing, in order to ensure impartiality and integrity in the selection process.

Implementing the publishing process. The process of establishing publishing criteria and processes for an entry-level scientific journal, and then selecting, preparing, and publishing student work is probably the most unique and difficult process in this program. It is helpful if the lead teacher(s) has support from the consultant for this. Training, exemplars, and communication with the consultant during the first rounds of publishing will increase the efficiency of this process. The details of the training process for establishing publishing criteria, the selection process, and the paper writing and revision process are based on an exemplar Student Research and Publishing Program. These will not be discussed here, as they are beyond the scope of this Model for Implementation.

Phase 4: Establishment – *Establishment and Expansion of the Student Research and Publishing Program*

It is important that a school that is implementing the Student Research and Publishing Program understand that this program changes the culture of a science program. Rather than being only *consumers* of science content, students and teachers become *creators* of new knowledge, actively and authentically participating in the global scientific community when a paper is published. As it represents a change of culture, the full embedding of the SRPP into the science program can be expected to take years. A long-term commitment to the program is required. Difficulties can be expected and should not be allowed to result in the abandonment of the program. Once the SRPP is well embedded within the science subject(s) of the original lead teacher(s), the school may consider expanding the SRPP to other science subjects, or even to other courses which might conduct original research, such as Psychology.

The expansion of the SRPP into new subjects can be done following the same process as outlined in this Model for Implementation.

Implementation Timeline

The timeline for implementation of the Student Research and Publishing Program at a school is highly dependent on the situation at that school. However, for planning and projection purposes, estimates of the time needed for each phase of the process can be made.

Phases 1 and 2 together, making the decision to adopt the SRPP and then preparing for implementation, would be expected to take approximately one to two years: one year for a school that had a science program with the IRP's already integrated into it, and two to three years for a school that needed to implement IRP's into their science program.

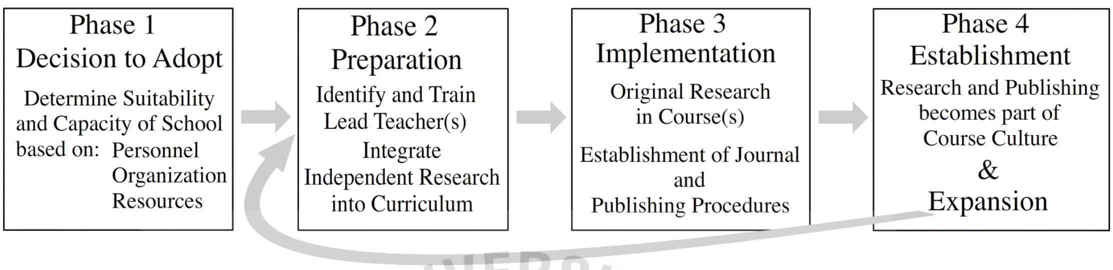
Phase 3, implementation of the SRPP, would be expected to take another one to two years, again depending on the situation of the school. A school that had a strong culture of research already established could probably see its first issue of a Journal after only one year, while a school where both teachers and students had little experience with independent research could be expected to take two or more years to publish its first papers.

Phase 4, embedding of the SRPP into the culture of the school, is expected to take between two and five more years, with consideration of expansion into other subjects recommended after that period.

Summary of the Model for Implementation

Implementation of the Student Research and Publishing Program in Secondary School Science can be broken into four phases, illustrated in Figure 4.3.

Figure 4.3: Summary of the Structure of the Model for Implementation of the Student Research and Publishing Program in Secondary School Science.



1. **Decision to Adopt: Determining the suitability of the Student Research and Publishing Program for a school.** The characteristics and capabilities of the school must be determined to be suitable for the implementation of the SRPP. Schools lacking key requirements are recommended not to implement the SRPP.
2. **Preparation for Implementation of the Student Research and Publishing Program.** This phase involves identifying and training the lead teachers who will implement the program, as well as ensuring that the curricular program includes an Independent Research component in courses at all levels.
3. **Implementation of the Student Research and Publishing Program.** This involves integrating original student research into all courses, with the awareness of the possibility of having work published. Then a Journal must be established, with its attendant selection, writing, and publishing processes defined and implemented.

4. **Establishment and Expansion of the Student Research and Publishing Program.** Over time, a culture of scientific research and publishing will be established within the school, and the expansion of the program into other subjects (assuming it was initially implemented in only one or two subjects) can be considered. Expansion into new subjects will follow a model similar to initial implementation.

The Model for Implementation of a Student Research and Publishing Program in Secondary School Science was constructed based on data gathered from students, teachers and administrators involved in a currently successful Student Research and Publishing Program in Secondary School Science. Use of the Model by a secondary school is expected to lead to the establishment of a successful Student Research and Publishing Program in the Sciences.

CHAPTER V

CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

This study has attempted to accomplish two goals: firstly, to describe the effects of the Student Research and Publishing Program established at ISB in a number of educationally important areas, and secondly, to develop a Model for Implementation of the SRPP in other schools.

The Student Research and Publishing Program in Secondary School Science is a program unique in the world. The SRPP established at ISB is integrated into the two-year IB Physics course. Students in the SRPP-based course are introduced to a three-part model of the process of science consisting of 'Mastering current knowledge', 'Creating new knowledge', and 'Publishing the newly created knowledge'. This model is used as an organizing structure and focus for the course. Students are guided through the levels of scientific inquiry, culminating in open inquiry, in which students are required to design and conduct authentic, original investigations and report on their findings, with the understanding that there is a possibility of their work being selected for publication. Students whose investigations are selected for publishing in the peer-reviewed, entry-level *Journal of Science* work with their teacher and the Editor of the *Journal* to write and publish a paper.

In the first part of the study, the effects of the SRPP on student outcomes in four areas was investigated: Science-related attitudes, Understanding of the nature of science, Research and publishing skills and attitudes, and Development of 21st Century skills. This was done by comparing students in the SRPP-based IB Physics courses with students in the standard IB Physics courses at ISB. A series of four surveys and a rubric-based assessment instrument were used.

In the second part of the study, insights obtained from the study of a Trial Expansion of the SRPP were combined with the results of a thematic analysis of a series of interviews to develop a Model for Implementation of the SRPP in other secondary schools. This Model was subjected to expert validation, and the feedback was used to revise and improve the final Model.

In this chapter, the findings of each of the objectives will be summarized, the results of the study discussed, and recommendations made for further action.

Conclusions

The first four objectives of the study addressed the effects of the established SRPP on student outcomes in four areas of educational interest. The conclusions of the findings for each of these objectives will be presented, giving a summary of the benefits and limitations of the SRPP in affecting student outcomes. The fifth and final objective aimed to develop a Model for Implementation of the SRPP using the findings of a Trial Expansion of the SRPP in conjunction with interviews with people with a range of expertise and experience of the SRPP. A summary of the validated Model will be presented.

Objective 1: To Determine the Effect of the SRPP on Students' Science-Related Attitudes

The SRPP was shown to have little significant effect on the science-related attitudes measured in this study. It was shown that there was no significant effect on students' Attitudes toward the Social Implications of Science, the Normality of Scientists, or Scientific Inquiry. There was also no demonstrated effect on students' Adoption of Scientific Attitudes, or their Leisure or Career Interest in Science. A significant positive correlation of students' Enjoyment of Science Lessons with enrollment in an SRPP-based course was shown. It is not surprising that the SRPP, with its limited focus, would have no significant effects on these student attitudes. Student science-related attitudes are strongly influenced by student personality, interests, goals and the sum of their experiences in science classes. These influences were very similar for the two groups compared in this study. And the SRPP, with its exclusive focus on authentic research and publishing, would be unlikely to strongly influence the attitudes addressed in this study.

Regarding students' Enjoyment of Science Lessons, it is unlikely that the SRPP was the cause of the demonstrated difference, due to the limited role it plays, in terms of focus and time, in the IB Physics course. 'Enjoyment of Science Lessons' would be affected by the sum of the time and activities experienced by students in the course, not just the focus of the independent research projects. It is probable that the cause of this correlation lay outside of the SRPP, that teacher personality, behaviors, and teaching style were a more likely cause of the observed difference, given that all SRPP students were taught by one teacher, while non-SRPP students were taught by two other teachers,

Objective 2: To determine the effect of the SRPP on students' understanding of the Nature of Science

Six aspects of the Nature of Science were studied: Observations and Inferences, Change in Scientific Theories, Scientific Laws vs Theories, Social and Cultural Influence on Science, Imagination and Creativity in Scientific Investigations, and Methodology of Scientific Investigation. The SRPP was shown to have no effects on any of these six aspects of the Nature of Science.

Given that the SRPP gives students much more authentic and complete experience of the nature and processes of science, one might be surprised by this finding. However, Abd-El-Khalick & Lederman (2000) showed that implicit NOS instruction is unsuccessful, and only explicit instruction on the Nature of Science will affect student understanding. The SRPP provides no explicit instruction on NOS, and so would be expected to demonstrate little effect on student understanding of NOS.

One point of interest was the very low understanding demonstrated by both groups in their understanding of the difference between scientific laws and theories. This same low result was also demonstrated in other studies (Liang et al, 2008; Clough et al, 2010; Saderholm, 2007). Saderholm (2007) suggests that this lack of understanding was due to the fact that the colloquial definitions of the terms 'theory' and 'law' used by students is very different from the true scientific definitions of these terms.

Objective 3: To Determine the Effect of the SRPP on Students' Experimental Research and Publishing Skills and Attitudes

Objective 3 focused directly on the heart of the SRPP: research and publishing skills and attitudes. This objective was investigated through the use of two instruments, one of which, SSRSSA, was given to both groups in the study and the second, AESP, given only to students in the SRPP. It was shown that the SRPP had a very significant, positive effect on a wide range of skills and attitudes related to the research and publishing processes.

We start by looking at the conclusions that can be drawn from the results of the SSRSSA instrument. It was shown that the SRPP had a significant positive effect on students' ability to Think and Work Like a Scientist. This included students' abilities to formulate research questions, design investigations, analyze data, identify limitations in the conclusions, and understand related theory. These are all crucial skills that are important to impart to science students.

The results also indicated that students in the SRPP experienced significantly greater Personal Gains related to experimental work. These benefits included increases in students' comfort in working collaboratively, and in taking greater care in conducting procedures during investigations. Other significantly greater gains reported included gains in understanding what everyday research is like and in developing patience with the slow pace of research. It also included gains in students' confidence in their ability to perform well in future science courses, and in their ability to contribute to science. The SRPP increases student gains in all these areas that are important in science education, and it does this for students still in secondary school.

The next area in which the SRPP was shown to have a significant effect was in increased Gains in Skills related to experimental research work. The skills shown to gain benefit included working with computer probes and calibrating instruments, as well as using statistics to analyze data. It also included time management, keeping a detailed lab notebook and making careful observations. Finally, it increased student skills in understanding journal articles and in writing scientific reports and papers. That last skill noted is of great importance, as students' writing ability is crucial to their future academic and professional success in all fields, not just science. The SRPP has been shown to significantly increase students' ability to write reports and papers during their two years in IB Physics. To quote a student, "Doing the many researches and write ups that were expected of us is one of the most beneficial things for me in high school. Not only did I learn to write in detail, it also helped me improve my scientific writing skills by leaps and bounds."

A fourth area in which the SRPP was shown to have a significant effect on students' outcomes was in Attitudes and Behaviors related to experimental research work. These included increases in students feeling responsible for their research projects and thus being willing to work extra hours on their research. It also increased students' creative thinking about their research, leading them to try out new ideas in their research. Finally, the SRPP increased the level at which students felt they were engaged in real-world science research, leading to their feeling like a scientist and feeling like they were part of the scientific community. An additional aspect that was affected was students' experience in their science class. SRPP students reported higher levels of satisfaction with their working relationships with lab partners and their teacher, as well as with the amount of time spent doing meaningful research, and with their experimental research experience overall. As before, these are all valid and important goals in science education, and the SRPP has been shown to significantly improve student gains in these areas.

The SRPP was also shown to have significant positive effects on students' feelings of being prepared for more advanced scientific research and coursework, leading to more students planning on pursuing STEM fields in university and professionally. This is a key finding, as many countries face shortages of qualified STEM workers. The SRPP has been shown to clearly and significantly increase students' desire and levels of preparedness to enter STEM fields.

The SRPP was also shown to have a positive effect on students' motivation to participate in the research aspects of the IB Physics course. Students' in the SRPP were more likely to be motivated by the opportunity to gain authentic, hands-on experience in research, allowing them to explore their interest in science and helping clarify whether or not they wanted to pursue a science-related career.

The second instrument, AESP, was only administered to students in the SRPP, so no comparisons with non-SRPP students can be made. The conclusions that can be drawn are thus more descriptive. The first conclusion which can be drawn is that the opportunity to publish a paper in the *Journal of Science* seemed to have a less-than-expected effect on the effort that students put in to various aspects of designing, conducting, analyzing and reporting on their research projects. Students reported reasons including: "It is my nature to produce my highest caliber work for all assignments that matter to me", and "I did my independent research for my IB Physic's (sic) class, not for the sake of the *Journal of Science*." Students seemed to be motivated to put in their best efforts due to personal character or their desire to do well in the course. Other reasons included: "my level of interest in physics was not extremely high", and "It was a lot of extra work and I wasn't sure if writing scientific papers was something I'd do much in the future." Students' level of interest in publishing is linked to their level of interest in science and in pursuing a career in science. Supporting this observation, a further result was that, unsurprisingly, students' level of interest in publishing a paper in the *Journal* was strongly correlated to their Science and Math Coefficient, which attempted to measure students' ability in and affinity for science. Students with high levels of interest in publishing explained their reasons as follows: "Publishing a paper is an honor. The experience of writing a near-professional paper, publishing it, and being a part of the scientific community made me extremely interested," "A unique opportunity to write a scientific paper before entering university," and, ever the pragmatists, "Prestige of having published would look good on a college application." Students saw the opportunity to publish as a way to challenge themselves in a unique and rigorous way, to gain experience in a new skill, and, of course, being practical, to enhance their university applications. We can conclude that, while the possibility of publishing seems to mostly motivate the academically stronger students, for those students it is a powerful motivator.

The AESP also investigated the effects of the publishing process on students who were selected to publish a paper. Students reported that the process of publishing a paper in the *Journal of Science* had a "moderate effect" on a range of skills and attitudes, including: understanding journal articles, conducting data analysis, drawing conclusions, and presentation of results. About one-third of students responded that publishing had "Great Effect" on each of these aspects. Students reported that the publishing process had the greatest effect on their scientific writing ability, with 60% of students reporting that it had a "Great Effect" on their writing ability. Not only did the SRPP have a significant effect on all students' writing ability, compared to students not in the SRPP, but students who were selected to publish a paper reported even greater effects. These seem, to the author, important effects, given the fact that publishing a paper was only a 10-hour time investment during a two-year program. Students elaborated on the effects of the publishing process as follows: "Publishing a paper in the *Journal of Science* developed my ability to write for scientific and academic assignments while at University," "I was able to see what kinds of mistakes (in writing) I was making as a student, and I made sure to note those flaws and never make them again," and "It forced me to read scientific papers that are much too complex for me to comprehend fully, so I have learned to parse information from these papers in the best way that I could."

It can be concluded that the *Journal of Science* and the possibility of publishing has little direct impact on the majority of students. Yet the *Journal* is recognized as a crucial component of the SRPP, providing an end point to the model of the scientific process upon which the program is founded. Without the existence of the *Journal*, students' understanding and experience of the process of science would be incomplete. In the words of one student, "“The *JoS* was one of the most important aspects of ISB's science program when I was there. All the other aspects (IRPs, rigor, etc) are necessary, but the *JoS* takes all of that and ties it together into one crown jewel."

It can also be concluded that, for academically strong and motivated students, the *Journal of Science* and the possibility of publishing are recognized as valuable motivators, and for those who do publish a paper, gains are seen over a range of important and sophisticated skills.

We end with selected student quotes that illustrate student views on some of the more subtle and sophisticated benefits of the SRPP:

> "I feel that the independent experimental research we did in IB physics did a very good job of teaching us how to think creatively and be problem solvers for an area of research each student was individually interested in."

> "The experience enabled me to acquire skills including the ability to think logically, to plan and practically execute an individually established idea and to create a professional account of an investigation. These skills can be applied to almost any area of study and I expect it to help me greatly in the future."

> "I also discovered an affinity for seeking and learning new knowledge, which was inspired in part by experimental research at ISB."

> "Unsurprisingly, I think I didn't fully appreciate the value of the *Journal* as a high schooler. Four years later, and now having taken advanced courses in science that emphasize primary literature, I see how beneficial it was for me to go through the experience of publishing the results of even a simple physics experiment."

> "Publishing a paper for the *Journal of Science* is one of the highlights of my high school education and I feel very grateful for having had that opportunity."

The SRPP has been shown to have a significant positive effect on students' development of a range of research and publishing skills and attitudes. Development of these skills and attitudes is an important goal of science educators around the world. The SRPP accomplishes this goal.

Objective 4. To determine the effect of the SRPP on students' development of 21st Century Skills

The final objective addressing the effects of the SRPP on student outcomes looked at student development of 21st Century skills, as evidenced in students' IRP lab reports. The SRPP was shown to have no significant effect on four of the nine 21st Century skills assessed in this study. The four 21st Century skills, as assessed in IRP lab reports, which were shown to be unaffected by the SRPP were Effective Communication, Collaboration by appropriately placing itself within the context of other's research, Information Literacy, and ICT Literacy. This is unsurprising, as the standard IB Physics course incorporates a lab program that emphasizes effective analysis and reporting of the results. This means that students in the Control Group were adequately taught these skills as part of the standard IB Physics course, and the SRPP, only emphasizing a different focus for the standard IB lab program, would have done little to affect student development of these aspects of 21st Century Skills.

The SRPP was shown to have a significant effect on five of the nine 21st Century Skills assessed in this study. Students in the SRPP showed greater development of Creativity in experimental design ($p < 0.01$), Innovation in the implementation of the design ($p < 0.05$), Problem-solving skills in the conduct of the investigation ($p < 0.05$), Critical thinking in its analysis and evaluation of the results,

($p < 0.10$) and, Flexibility, initiative, and independence ($p < 0.05$), as assessed from their Independent Research Project Lab Reports.

The SRPP, with its emphasis on authentic, original research, would be expected to encourage the development of these skills in students. Students are designing, conducting, and analyzing research on original questions of personal interest, leading to high levels of engagement. Often these involve innovative procedures that must be designed and modified by the students. And the results are often unexpected or ambiguous, leading to students to try multiple approaches in analysis and interpretation. These attributes of the SRPP lab program lead to the demonstrated increase in students' development of higher-level skills like creativity, innovation, problem-solving, critical thinking, and flexibility, initiative and independence.

Objective 5: Development of a Model for Implementation of a Student Research and Publishing Program in Secondary School Science

Looking at the conclusions to Objectives 1-4 above, the Student Research and Publishing Program in Secondary School Science has been shown to yield significant positive results over a range of student research and publishing abilities and attitudes. It is expected that schools that are made aware of this program may be interested in implementing it.

The following is a Model for Implementation of the SRPP, developed with input from the results of the study of the Trial Expansion along with the interviews with a range of experts with experience of the SRPP. This Model can be followed by secondary schools during implementation of a Student Research and Publishing Program in Science. It is expected that using this Model for

Implementation at a school will result in a successfully established Student Research and Publishing Program in Secondary School Science at that school. A successfully established Program is defined as having the characteristics and outcomes of the currently established SRPP described in detail in Chapters 1 and 3. This includes using the simplified SRPP model of the Process of Science as a focusing structure for the course. It also includes having Independent Research Projects (IRP's), where students conduct authentic, original, experimental research, integrated into all courses participating in the Program, as well as *Journal* papers being published regularly. A successful SRPP will have student outcomes similar to those described above. The final, validated Model for Implementation of the SRPP is described in detail in Chapter 4, and will only be summarized here. The Model consists of four Phases as described in the following sections.

Phase 1: Decision to Adopt - *Determining the Suitability of the Student Research and Publishing Program for a School*

The first step in the implementation process is to verify the suitability of the SRPP for a particular school. It is clear that this program is not suitable for all schools, and that not all schools have the capacity to successfully implement it. It is thus necessary for a school to conduct a study to determine whether the SRPP could be successfully implemented.

The following are the characteristics of a school that is likely to benefit from the SRPP and at which implementation has a higher chance of success. The needed Organizational Characteristics needed in a school include: administrative flexibility, curriculum incorporating significant time for lab work with open-inquiry a regular feature, and relatively small class sizes, preferably fewer than 25 students per class.

The Physical and Capital Resources required include: Adequate laboratory space and lab equipment typical of a secondary school in developed countries, and funding for stipends and lab equipment necessary to support the SRPP. The ability to source unusual equipment on a relatively short time scale is helpful.

A school needs to have students, teachers, and administrators with certain characteristics in order to successfully implement the SRPP. There must be a significant proportion of students at the school who value education and are interested in pursuing science as a career. It is not necessary to be a selective school with gifted students. Students who are motivated to excel and are committed to science are all that is needed to be able to implement a successful SRPP. The school must have one or more teachers who are passionate about teaching science and are skilled in teaching open-inquiry in science. Importantly, and it must be emphasized that this point is crucial, the teacher(s) selected to implement the program must be passionate about, and strongly committed to, implementing the Student Research and Publishing Program. If these key criteria are not met, it is unlikely that a school will be successful in implementing the program. Finally, administrators at the school should understand the SRPP and see the value in it, commit adequate resources to supporting it, and, if necessary, work to clear any institutional roadblocks to implementing the program.

If conditions at the school are in close alignment with those outlined above, it can be concluded that implementation of the Student Research and Publishing Program stands a high chance of success. It must be emphasized that the lack of any factor described as crucial above is expected to lead to failure in the implementation of the SRPP, and implementation is not recommended.

Phase 2: Preparation - *Preparation for Implementation of the Student Research and Publishing Program*

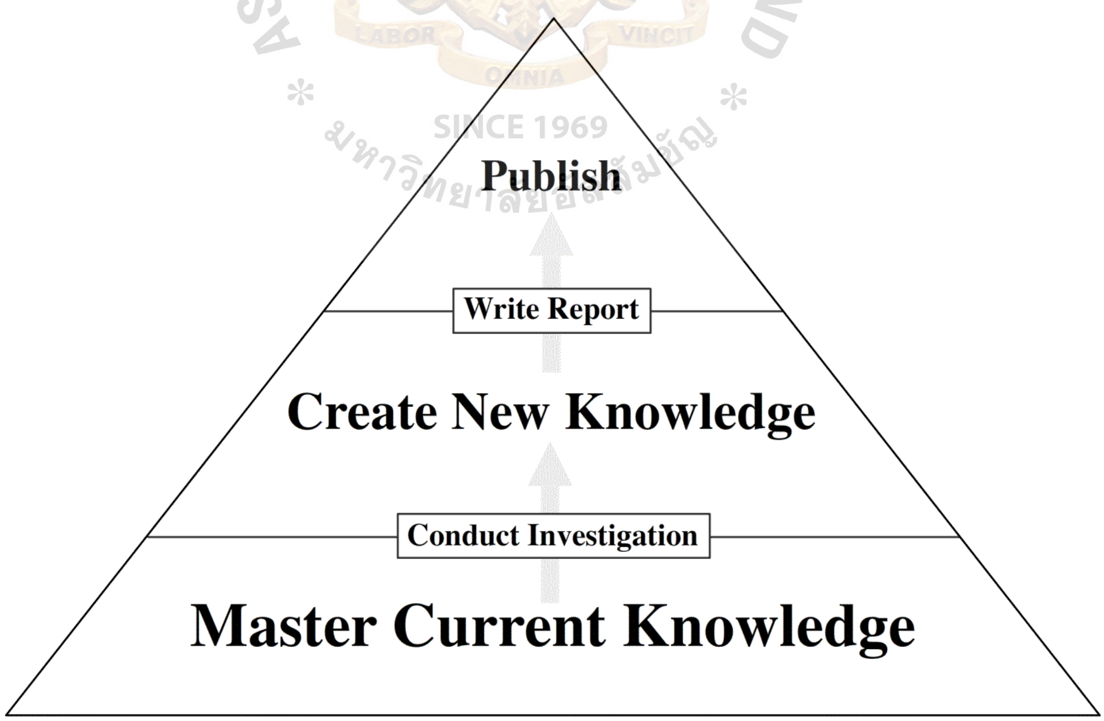
The preparation necessary for implementation of the SRPP varies with the school. Each school will find itself in a unique situation, so each school will have a unique path to implementation of the SRPP. However, certain general areas of preparation can be identified.

Schools must start by identifying the lead teacher or teachers for implementation of the SRPP. This is probably the most difficult step in the whole process. Given that the drivers of this program are teachers, it is impossible to implement without the leadership of a teacher who is scientifically and pedagogically competent, and is passionate about, and committed to, establishing the SRPP at the school. This point cannot be emphasized strongly enough.

Once a lead teacher has been identified, training in implementation of the SRPP is required. A consultant with experience in running a successful program must be engaged to train the lead teacher. The training may take the form of a short initial workshop, followed by continued support via electronic communication or may be set up as a series of exchange visits over the course of implementation. The training will ensure that the lead teacher understands the benefits of the program, including expected student outcomes and long-term changes in school culture, develops an in-depth understanding of the details of the program, and develops expertise in the skill set needed to implement and run the program. The use of an established program as an exemplar of all the components and processes involved in the SRPP is beneficial in this process. The lead teacher(s) could study all aspects of that program as part of the training process.

The next step in implementation of the SRPP is preparing the curricular research program. It is essential that the philosophy and organization of the science program be aligned with the SRPP. The SRPP course(s) must be (re-)designed to focus not only on content mastery, but on the process of science as a whole. It is recommended that the simplified SRPP model of the scientific process, shown again in Figure 5.1, be used to help students understand the focus of the course. The lab component of each course must prepare the student for the culminating Independent Research Project, in which students design and conduct original research within the context of the course content to create new knowledge, with the view to potentially publishing their results.

Figure 5.1: The simplified SRPP model of the scientific process.



It is also recommended that a resource be developed that guides students in how to design, conduct, and report on IRP's. This 'Research/Writing Guide' describes best-practice in designing and conducting IRP's, and gives detailed guidelines on the requirements for writing the report for the IRP. The teacher should refer to this resource regularly to help students as they plan and conduct their research and report their findings. Finally, a system offering compensation of some form for the teachers involved, whether it be financial or time-based, should be established. It is also recommended that protocols for recognition of achievement for students who publish their work be considered.

Phase 3: Implementation - *Implementation of the Student Research and Publishing Program*

Implementation of the SRPP should start with implementation of the in-course research part of the program in all courses, starting with the first year in the upper secondary school which must have an IRP incorporated into them. As noted above, schools with well-established IRP programs will need to spend little time on this step, while other schools might need to expend significant effort. After the research aspect of the program has been established in the science program for a year or more, it is expected that some students will begin to produce work that is worthy of consideration for publishing. Now is the time to establish the capacity to publish student work.

An online journal must be established, with publishing procedures defined. The process of establishing publishing criteria and processes for an entry-level scientific journal, and then selecting, preparing, and publishing student work is probably the most unique and difficult process in this program. It is helpful if the lead teacher has support from a consultant for this. Training, exemplars, and communication with the consultant during the first rounds of publishing are crucial.

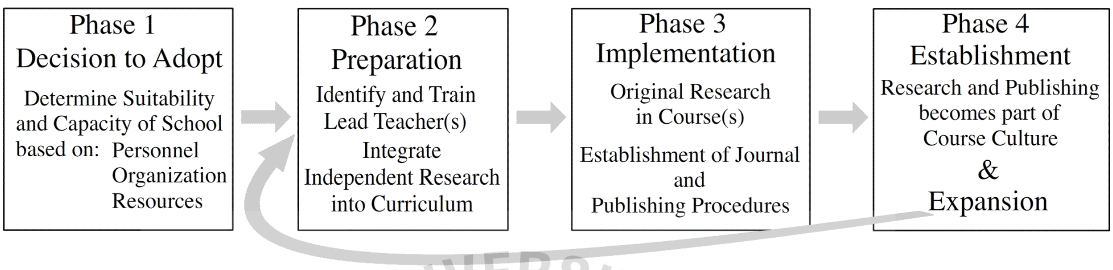
An important aspect of the scientific publishing process is the review process. It is crucial that knowledgeable and respected Reviewers be selected and agree to participate in the program. The reviewers must then be trained regarding the publishing guidelines, the process of reviewing the original submitted work, and then reviewing and approving the final paper.

Phase 4: Establishment – ***Establishment and Expansion of the Student Research and Publishing Program***

It is important that a school that is implementing the Student Research and Publishing Program understand that this program changes the culture of a science program. Rather than only being consumers of science content, students and teachers become creators of new knowledge, actively and authentically participating in the global scientific community when a paper is published. As it represents a change of culture, the full embedding of the SRPP into the science program can be expected to take years. A long-term commitment to the program is required. Difficulties can be expected and should not be allowed to result in the abandonment of the program. Once the SRPP is well embedded within the science subject of the original lead teacher, the school may consider expanding the SRPP to other science subjects or even to other courses, such as Psychology, which might conduct original research. The expansion of the SRPP into new subjects can be done following the same process as outlined in this Model for Implementation.

A visual summary of the Model for Implementation of the Student Research and Publishing Program in Secondary School Science is illustrated in Figure 5.2, below.

Figure 5.2: Summary of the Structure of the Model for Implementation of the Student Research and Publishing Program in Secondary School Science.



Discussion

This study begins with an investigation into the effects of the established SRPP on student outcomes in four educationally important areas: science-related attitudes, understanding of the Nature of Science, research and publishing skills and attitudes, and development of 21st Century Skills. Students in the SRPP were compared to students experiencing the standard IB Physics course, with no SRPP. Both groups also experienced the standard inquiry-based science program in grades 9 and 10. The established SRPP at ISB is integrated into the IB Physics course. It has been shown that the SRPP is well grounded in educational research and theory.

The SRPP uses the simplified model of the process of science (Mastering current knowledge, Creating new knowledge, and Publishing the newly created knowledge) as a focusing lens for the students in the course. While most models of the process of science focus on the investigative practices of expert scientists (Harwood, 2004), the SRPP model takes into account the differences between novices and experts (Kirschner et al, 2006; Glaser & Chi, 1988), allowing teachers and students to more effectively balance the process of science to meet the needs of novice secondary school science learners (Chiappetta & Adams, 2004).

The SRPP starts with an inquiry-based learning science program that leads students from confirmation inquiry to open inquiry (Banchi & Bell, 2008; Chinn & Mahotra, 2002) via a scaffolded series of investigations (Gröschner, Lockhart & Le Doux, 2005; Hmelo-Silver & Nagarajan, 2002), with an online "Writing Guide" as a student resource. The investigations culminate in authentic, original, Independent Research Projects (Wang et al, 2012; Wang, Dyehouse, Weber & Strobel, 2012; Edelson, 1998).

A unique aspect of the SRPP is the *ISB Journal of Science*, an entry-level, peer-reviewed scholarly journal. Journals such as this have been advocated as increasing student learning for a range of outcomes. (Guilford, 2001; Burns & Ware, 2008; Ho, 2011). Students in the SRPP are informed of the possibility of publishing a paper on the results of their IRP's in the *Journal of Science* at the beginning of the course. They are regularly reminded of the opportunity and encouraged to aim for that goal, as this is expected to increase student engagement in the research process (Jungck, 2004).

The process of publishing a paper in the *JoS* begins with the teacher selecting IRP's that might meet the publishing criteria. These IRP's are then submitted to the Editor of the *Journal* and are subjected to a Review process. The Reviewer decides whether to accept the work for publishing or not. Selected students then go through a drafting and revising process with their teachers and the Editor to write a paper (Chancey, 2003), which is then published in the *Journal*.

Having grounded the SRPP in the context of accepted educational research and theory, we now turn to look at the effects of the SRPP on student outcomes. The first area of student outcomes, science-related attitudes, showed no effect by the SRPP. Trumper (2006) showed that student attitudes and interest in science was affected by increased levels of inquiry-based learning in science classes. Numerous other studies have found similar positive effects of inquiry-based learning (Bryang, 2006; Geier, (2006); Tsai & Tuan, 2005). While at first glance the findings of these studies seem to contradict the results of this study, knowing that the Control Group also experienced a strong inquiry-based science program allows us to understand the lack of difference found in this study. The second area, understanding of NOS, similarly showed no effect from the SRPP. Scallon (2006) compared effects of scaffolded guided inquiry with authentic scientific investigation. This is similar to the current study with the Control Group experiencing scaffolded guided inquiry and the SRPP group experiencing authentic investigations. Scallon found that students in the authentic investigations program showed more gains in student understanding of the process of science. While process of science and NOS are not identical, one might expect to see similar results in this study. Similarly, Ayar and Yalvac (2010) believe that the use of authentic learning environments, similar to those of the SRPP, is expected to lead to improved student understanding of the nature of science. However, Abd-El-Khalick & Lederman (2000) showed that implicit NOS instruction is unsuccessful, and only explicit instruction on the Nature of Science will affect student understanding. The SRPP provides no explicit instruction on NOS, so would not be expected to have any effect on students' understanding of NOS, as was shown.

The final two areas investigated, research and publishing skills and attitudes, and 21st Century Skills, both showed that the SRPP resulted in significant positive effects on students' outcomes. These results have been strongly supported by research into programs with similar characteristics. Edelson (1998) found that students engaging in authentic science practice showed increased appreciation of the uncertainty of scientific findings, increased commitment, and increased feelings of being part of the scientific community. All these student outcomes were shown to be produced in the SRPP as well.

Other demonstrated effects of the SRPP which have been supported by other researchers include: increased ability to define a research question (LaBanca, 2008), ability to design and conduct investigations (Hunter et al, 2007, Lopatto, 2007), ability to use lab equipment (Le, 2010), analytical thinking (Scallon, 2006; Seymour et al, 2004; Lopatto, 2007), confidence in ability to perform well in future courses (Russell, 2010), understanding of the investigative process (Seymour et al, 2004), increased desire to enter STEM fields (Russell, 2010; Roberts & Wassersug, 2008; Winkleby et al, 2009), increased ability to think and work like a scientist (Weston, 2012b), creative thinking, initiative, and flexibility (Osborne & Karukstis, 2009; Hunter et al, 2007; Russell, 2010), and gains in a range of higher-order thinking skills (Dempster, 2003; Osborne & Karukstis, 2009), improved communication and writing skills (Ho, 2011) to name a few. Clearly, the student outcomes found to be affected by the SRPP are consistent with that found in programs with similar characteristics, increasing confidence in the reliability of these results.

There are some weaknesses and limitations to this study that must be acknowledged. Firstly, the fact that the study was conducted with existing, self-selected, and unequal populations, rather than having the populations randomly assigned to equal-sized Control and Treatment Groups is an issue. This study cannot be considered an experiment in any real sense, and must be acknowledged to be merely a study of two existing, unequal populations. This decreases levels of confidence in the findings.

Secondly, the fact that all students in the Treatment Group had one teacher, while the students in the Control Group had two teachers, different from the Treatment teacher, is a weakness in the study. Again, because this was a study of an existing population in a working program, this could not be avoided. But it is a weakness nonetheless. While it is conceivable that all differences found were caused by the difference in teachers, not by the SRPP, the author contends that this is unlikely. The fact that not all areas studied showed differences, coupled with the fact that the very significant differences found were directly related to the focus of the SRPP, and supported by finding of other researchers, leads the author to claim, with fairly high levels of confidence, that the SRPP was the cause of the demonstrated differences.

Finally, the low rate of participation consent in the Control Group led to sample sizes being below the 95 % Confidence Level (Krejcie & Morgan, 1970). While this must be acknowledged as lowering levels of confidence in the results, the author contends that the very high significance found in most of the demonstrated effects ($p < 0.01$ in most cases) lead to the conclusion that the results are reasonably reliable.

It has been shown that the SRPP has no effects on science-related attitudes and understanding of NOS, compared to students in the standard inquiry-based science program at ISB. However it was shown that the SRPP has very significant positive effects on a range of research and publishing skills and attitudes, along with select 21st Century skills, that are important goals for science education. The value of the SRPP has been clearly established. Establishing the SRPP in other programs and schools is therefor expected to be a very desirable goal, as it will lead to increased student gains in a range of important areas. But how easy is this to accomplish? What is the feasibility of implementing the SRPP in other schools?

The Model for Implementation of the SRPP in other schools was developed as a guide for schools who are interested in increasing their students' gains in these demonstrated areas. The Model is a blueprint, or outline, guiding schools through the process of implementation. Recognizing that the SRPP is not appropriate or feasible for all schools, the Model begins with a description of the characteristics and conditions of a school at which the SRPP is expected to be feasible and beneficial. Next, the Model describes the steps needed to prepare for implementation. The beginning of the implementation process is then described, with suggestions for increasing chances of success. Finally, guidelines on strategies and adjustments that are required for the long-term, successful establishment of the SRPP in a school are discussed. The Model is described in detail in Chapter 4.

Recommendations

Given the strongly significant demonstrated effects of the SRPP on a range of important student outcomes, it is recommended that implementation of the SRPP be considered in other programs and schools. Following the developed Model for Implementation, schools must first determine the suitability of the SRPP for their situation, and their capability to successfully implement the SRPP. Upon that determination, it is recommended that schools follow the guidelines in the Model for the Preparation, Implementation, and Establishment phases.

A second recommendation is for further study of the SRPP and its effects. The SRPP is a program that is, as far as the author could ascertain, unique in the world. This study is the first study of the established SRPP at ISB. It is recommended that further studies of the established SRPP be conducted. Aspects of the program that could be studied include its effects on other areas of student outcomes, its effects on teachers, its effects on school culture, and the processes of its implementation and continued functioning.

A third recommendation involves the implementation of the SRPP in other programs and schools. Given that the developed Model for Implementation proposed in this study has never been tested, much could be learned from studying the actual implementation process. It is recommended that any school that chooses to implement the SRPP should study the process of implementation, using the findings to revise and improve the Model for Implementation developed in this study.

Finally, once the SRPP is established in other programs and other schools, it is recommended that studies be conducted on the effect of these programs on student outcomes similar to those addressed in this study. It would be valuable to establish how varying conditions in different schools and in different programs impact on effects of the SRPP. These findings would increase our confidence in our understanding of the effects of the SRPP, and would lead to a more complete picture of the effect of various conditions on student outcomes.

REFERENCES

Abd-El-Khalick, F. (2001). Embedding Nature of Science in Preservice Elementary Science Courses: Abandoning Scientism, but... *Journal of Science Teacher Education*, 12 (3), 215-233.

Abd-El-Khalick, F., & Lederman, N. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, 22(7), 665-701.

Abd-El-Khalick, F., Bell, R. & Lederman, N. (1998). The Nature of Science and Instructional Practice: Making the Unnatural Natural. *Science Education*, 82(4), 417-436.

Aclufi, A. (2005). *Doing Science: The Process of Scientific Inquiry*. National Institutes of Health. Retrieved from: science.education.nih.gov/customers.nsf/MSInquiry statestds.htm.

Aitken, E. N., & Pungur, L. (2005). *Literature synopsis: Authentic assessment.* Alberta: University of Alberta. Retrieved from: edc.gov.ab.ca/k_12/special/aisi/ pdfs/Authentic_ Assessment_UofAb_UofL.pdf.

American Association of School Librarians (AASL). (2009). *Standards for the 21st-century learner in action*. Chicago, IL: ALA.

Anderson, L. W. & David R. Krathwohl, D. R. (Eds.). (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Boston, MA: Allyn & Bacon.

ASCD. (2007). *The learning compact redefined: A call to action, a report of the Comission on the Whole Child*. Alexandria, VA: ASCD.

Ayar, M., and Yalvac, B. (2010). A Sociological Standpoint to Authentic Scientific Practices and its Role in School Science Teaching. *Journal of Kirsehir Education Faculty*. 11(4), 113-127.

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children*, 46(2), 26–29.

Bloom, B. & Krathwohl, D. (1956). *Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: Cognitive Domain*. NY, NY: Longmans, Green.

Bransford, J. D., A. L. Brown, and R. R. Cocking, (Eds). (2000). *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Research Council.

Braun, V. and Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology* 3 (2): 83. doi:10.1191/1478088706qp063oa.

Broad Street Scientific. (2014). Retrieved from: http://www.ncssm.edu/bss/.

Bryant, J. (2006). Assessment results following inquiry and traditional physics laboratory activities. *Journal of College Science Teaching*, 35(7), 56-61.

Burns, S. & Ware, M. E. (2008). *Undergraduate student research journals: Opportunities for and benefits from publication*. In R. L. Miller, E. Balcetis, S. T. Barney, B. C. Beins, S. R. Burns, R. Smith, & M. E. War (Eds.) (2008). *Developing, promoting, & sustaining the undergraduate research experience in psychology* (pp. 253-256). Washington, DC: American Psychology Association.

Buxton, C.A. (2006). Creating contextually authentic science in a low-performing urban elementary school. *Journal of Research in Science Teaching*, 43(7), 695-721. In Steward, J. (2007). *Research Experience and Inquiry: Uses and Effects of Authentic Environments in Science Education*. Retrieved from ProQuest Digital

Dissertations. (UMI 3291067).

Campbell, D. (2000). Authentic Assessment and Authentic Standards. *The Phi Delta Kappan*: 81(5), 405-407.

Carpi, A. & Egger, A. (2011). The Nature of Scientific Knowledge," *Visionlearning* Vol. POS-3 (2). Retrieved from: www.visionlearning.com/library/module_viewer.php?mid=185.

Chancey, C. (2003). How should the Undergraduate Research Journal be Different? *American Journal of Undergraduate Research*. 2(2).

Chiappetta E. & Adams, A. (2004). Inquiry-based instruction: under- standing how content and process go hand-in-hand with school science. *Sci Teach* 71(2):46–50.

Chinn, C. & Malhotra, B. (2002). Epistemologically Authentic Inquiry in Schools: A Theoretical Framework for Evaluating Inquiry Tasks. *Sci Ed* 86:175–218. doi: 10.1002/sce.10001.

Clough, M. P., Herman, B. C., & Smith, J. A. R. (2010). *Seamlessly teaching science content and the nature of science: Impact of historical short stories on post-secondary biology students*. Sacramento, CA: Association of Science Teacher Educators Conference.

Cohen, L., Manion, L., & Morrison, K. (2000). *Research Methods in Education, 5th Ed*. London, Taylor & Francis.

Creswell, J. (2012). *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research, 4th Ed.* Boston: Pearson.

Creswell, J. & Clark, V. (2011). *Designing and Conducting Mixed Methods Research, 2nd Ed*. Thousand Oaks, CA: Sage.

Dempster, J. (2003). Developing and Supporting Research-Based Learning and Teaching Through Technology, Chapter 7, pp.128-158. In Ghaoui, C. (Ed.) *Usability Evaluation Of Online Learning Programs*. Information Science Publishing.

Dewey, J. (1910). Science as subject matter and method. *Science.* 31(787), 121-127

Directory of Open Access Journals, (DOAJ). (2014). Lund University Libraries. Retrieved from: www.doaj.org.

Donovan, S., & Bransford, J., (eds). (2005). *How students learn: history, mathematics, and science in the classroom / Committee on How People Learn, A Targeted Report for Teachers.* Washington, DC: National Academies Press.

Eales, J. (2014). Research and Publishing in a Secondary School Physics Program. *Thai Journal of Physics, Special Series 10 (SPC Conference 2014).* Bangkok, Siam Physics Society.

Eales, J. (Ed). (2007). *ISB Journal of Science* Retrieved from www.isb.ac.th/HS/JoS/.

Eales, J. (Ed). (2009). *ISB Scientific Writing Guide for IB*. Retrieved from: www2.isb.ac.th/hsscience/IB_Writing_Guide_1_2/OpenIBWritingGuide.htm.

Eales, J. (Ed). (2011). *ISB Scientific Writing Guide.* Retrieved from: www2.isb.ac.th /hsscience/Gen_Sci_Writing_Guide/ OpenWritingGuide%203.2.htm.

Edelson, D. (1998). Realising authentic science learning through the adaptation of scientific practice. In B. J. Fraser & K. G. Topin (Eds.), *International handbook of science education* (pp. 317-331). London: Kluwer.

Egan K (2005) *An imaginative approach to teaching*. San Francisco: Jossey-Bass.

Farney, T. A. & Byerley, S. L.(2010). Publishing a Student Research Journal: A Case Study. *Libraries and the Academy* 10(3), 323-335. The Johns Hopkins University Press. Retrieved from: Project MUSE database.

Fay, M., Grove, N., Towns, M., & Lowery, S. (2007). A rubric to characterize inquiry in the undergraduate chemistry laboratory. *Chemistry Education Research and Practice*, 8(2), 212-219.

Fencl, H., & Scheel, K. (2005). Engaging students: an examination of the effects of teaching strategies on self-efficacy and course climate in a non-majors physics course. *Journal of College Science Teaching*, 35(1), 20.

Foundations Vol. 2: Inquiry: Thought, views, and Strategies for K-5 Classroom. (2004). National Science Foundation Division of Elementary, Secondary, and Informal education (ESIE) Publication. Retrieved from: www.nsf.gov/pubs/2000 /nsf99148/htmstart.htm.

Fraser, B.J. (1981). *Test of Science Related Skills (TOSRA)*. The Australian Council for Educational Research Limited: Hawthorn, Victoria.

Geier, R., Blumenfeld, P., Marx, R., Krajcik, J., Fishman, B., Soloway, E. & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching*, 45, 922–939.

Gengarelly, L. & Abrams, E. (2009). Closing the Gap: Inquiry in Research and the Secondary Science Classroom. *J Sci Educ Technol*. 18:74–84 doi: 10.1007/ s10956-008-9134-2.

Gilbert, S. (2004). Points of view: should students be encouraged to publish their research in student-run publications? A case against undergraduate-only journal publications. *Cell Biol Educ*. 3(1):22-3.

Glaser, R., & Chi, M. T. H. (1988). Overview. In M. T. H. Chi, R. Glaser, & M. J. Farr (Eds.), *The nature of expertise* (pp. xv–xxviii). Hillsdale, NJ: Erlbaum.

Griffiths, R. (2004).Knowledge production and the research–teaching nexus: the case of the built environment disciplines. *Studies in Higher Education*. 29(6).

Gröschner, A., Heinz, J., Lipowski, K., & Seidel, T. (2010). *S-TEAM Baseline Report and Indicators Review*. Munich: S-TEAM. Retrieved from: www.ntnu.no/wiki/download/attachments/8324761/Deliverable+9a_STEAM_wp9.pdf?version=1&modificationDate=1277292972000.

Guilford, W. (2001). Teaching Peer Review and the Process of Scientific Writing. *Adv Physiol Educ* 25, 167–175.

Guterman, L. (2007). What good is undergraduate research, anyway? *Chronicle of Higher Education*, 53, A12.

Harwood, W. S. (2004). A new model for inquiry: Is the scientific method dead? *Journal of College Science Teaching*, 11,29-33.

Hensel, N (Ed). (2012). *Characteristics of Excellence in Undergraduate Research*. Council on Undergraduate Research.

Hmelo-Silver, C., Nagarajan, A. (2002). ''It's Harder than We Thought It Would be'': A Comparative Case Study of Expert---Novice Experimentation Strategies. *Sci Ed* 86, 219 – 243. doi: 10.1002/sce.10002.

Ho, A. K., *Creating and Hosting Student-Run Research Journals: A Case Study* (2011). Partnership: the Canadian Journal of Library and Information Practice and Research, 6(2).

Hodge, W. (2007). *Basic Education Curriculum Revisited: A Look at the Current Content and Reform.* Singapore: Ministry of Education, Training and Development Division.

Hunter, A., Laursen, S., Seymour, E. (2007). Becoming a Scientist: The Role of Undergraduate Research in Students' Cognitive, Personal, and Professional Development. *Sci Ed* 91, 36 – 74. doi: 10.1002/sce.20173.

Hunter, A., Weston, T., Laursen, S., and Thiry, H. (2009) URSSA: Evaluating Student Gains from Undergraduate Research in the Sciences. *CUR Quarterly* 29 (3).

Jenkins, A. (2001). *How (or Whether?) to Integrate Research into Classroom Taching for all Students and all Higher Education Institutions.* Innovations in Undergraduate Research and Honors Education: Proceedings of the Second Schreyer National Conference.

Jenkins, A. (2007, February 23). Doing research is a key element of learning: undergraduate research can transform the sector. *Times Higher Education Supplement*.

Jewell, S., (2011). *The Effects of the NXT Robotics Curriculum on High School Students' Attitudes in Science Based on Grade, Gender, and Ethnicity.* Retrieved from ProQuest Digital Dissertations.

Johnson, D., (1998). *Applied Multivariate Methods for Data Analysts.* Brooks/Cole, Pacific Grove, CA.

Journal of Emerging Investigators (JEI). (2014). Retrieved from: www.emerging investigators.org.

Journys: Journal of Youths in Science. (2012) Retrieved from: journys.org/.

Jungck, J. (2004). Undergraduates: Do Research, Publish! *Cell Biol Educ*. 3(1), 22-3.

Kalantzis, M. (2006). Changing Subjectivities, New Learning. *Pedagogies: An International Journal*, 1(1), 7-12.

Kalantzis, M., & Cope, B. (2004). Designs for learning. *e-Learning*, 1(1), 38–92.

Kirschner, P., Sweller, J., & Clark, R. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41, 75–86.

Krajcik, J., & Merritt, J. (2012). Engaging students in scientific practices: what does constructing and revising models look like in the science classroom? Understanding a framework for k-12 science education. *The Science Teacher*, 79(3), 38.

Krejcie, R. & Morgan, D. (1970). Determining sample size for research activities. *Educational and Psychological Measurements*, 30, 607-610.

LaBanca, F. (2008). *Impact of Problem Finding on the Quality of Authentic Open Inquiry Science Research Projects.* Retrieved from ProQuest Digital Dissertations. (UMI 3411366).

Laitko, H. (2000). *Great shifts in scientific thinking and human development in the last four hundred years: Evolution and impact of western science.* Paper presented to the Conference of the International Network of Scientists and Engineers for Global Responsibility (INES), Stockholm. Retrieved from: www.informatik.unileipzig.de/~graebe/Texte/Laitko-00.html.

Le, T. (2010). *Evaluation of the Long-term Impact of a Year long university High School Laboratory Research Program on Students' Interest in Science and Perceptions of Science Coursework.* Retrieved from ProQuest Digital Dissertations. (UMI 1484226).

Ledbetter, C.E. and Nix, R.K. (2002). *What do you think about science?* Retrieved from www.chemchapterzero.com/pdfs/AppendixJ1.pdf.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching,* 39, 497–521.

Liang, L., Chen, S., Chen, X., Kaya, O., Adams, A., Macklin, M., Ebenezer, J. (2006) *Student Understanding of Science and Scientific Inquiry (SUSSI): Revision and Further Validation of an Assessment Instrument*. Paper Prepared for the 2006 Annual Conference of the National Association for Research in Science Teaching (NARST). San Francisco, CA.

Liang, L., Chen, S., Chen, X., Kaya, O.N., Adams, A.D., Macklin, M., & Ebenezer, J. (2008). Assessing preservice elementary teachers' views on the nature of scientific knowledge: A dual-response instrument. *Asia-Pacific Forum on Science Learning and Teaching*, 9(1). Retrieved from: www.ied.edu.hk/apfslt/v9_issue1/liang.

Liang, L., Chen, S., Chen, X., Kaya, O.N., Adams, A.D., Macklin, M., & Ebenezer, J.. (2009). Preservice Teachers' Views about Nature of Scientific Knowledge Development: An International Collaborative Study. *Int'l Journal of Science and Mathematics Education,* 7:987-1012.

Llewellyn, D. (2005) *Teaching High School Science Through Inquiry*. Thousand Oaks, CA: Sage Publications.

Lockhart, A.& Le Doux, J. (2005). PARTNERSHIP for problem-based learning. *The Science Teacher,* Dec. 2005; 72, 9; pg. 29.

Lopatto, D. (2007). *Undergraduate Research Experiences Support Science Career Decisions and Active Learning*. Life Sciences Education. 6, 297–306

Lund, A. & Lund M., (2013). *Laerd Statistics*. Lund Research, Retrieved from: statistics.laerd.com.

Marshall, J. & Horton, R. (2011). The Relationship of Teacher-Facilitated, Inquiry Based Instruction to Student Higher-Order Thinking. *School Science and Mathematics*, 111(3), 93-101. doi: 10.1111/j.1949-8594.2010.00066.x.

Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist*. 59(1) p.14-19.

Mckenzie, W. (1996). *Investigative Learning in an Undergraduate Biology Laboratory: an Investigation into Reform in Science Education*. Retrieved from Proquest Digital Dissertations.

McKinney, L., & Sadler, T. (2010). Scientific research for undergraduate students: a review of the literature. *Journal of College Science Teaching*, *39*(5), 43.

Metz, S. (2006). Problem-based learning. *The Science Teacher*, 73(8), 8.

Miller M, Montplaisir L, Offerdahl E, Cheng F-C, Ketterling G. (2010). Comparison of views of the nature of science between natural science and non-science majors. *CBE Life Sciences Educ*. 9:45–54. doi: 10.1187/cbe.09-05-0029.

National High School Journal of Science (NHSJS). (2014). Retrieved from: nhsjs.com/

National Research Council (NRC). (1996). *National science educational standards*. Washington, DC: National Academy Press.

National Research Council (NRC). (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: National Academy Press.

National Science Foundation. (2003, March 30–April 1). Exploring the concept of undergraduate research centers: A report on the NSF workshop. Arlington, VA: Division of Chemistry, Office of Special Projects, Office of Multidisciplinary Activities, MPS Directorate. In Hunter, A., Laursen, S., Seymour, E. 2007.

Becoming a Scientist: The Role of Undergraduate Research in Students' Cognitive, Personal, and Professional Development. *Sci Ed* 91, 36 – 74. doi: 10.1002/ sce.20173.

National Science Teachers Association (NSTA). 2000. *The Nature of Science.* Retrieved from: www.nsta.org/about/positions/natureofscience.aspx.

NGSS Lead States. (2013). *Next Generation Science Standards: By States For States*. Achieve Inc. Retrieved from: www.nextgenscience.org/.

Osborne, J. M. and K. K. Karukstis. (2009). The benefits of undergraduate research, scholarship, and creative activity. In: M. Boyd and J. Wesemann (Eds.), (pp. 41-53). *Broadening Participation in Undergraduate Research: Fostering Excellence and Enhancing the Impact*. Washington, DC: Council on Undergraduate Research.

Rajagopalan, S., Vyjayanthi Sankar, V. & Batta, P. (2004). *An Overview of the Development of Learning Standards forScience and Mathematics Education: KG – 8*. Paper presented to epiSTEME - 1 Conference, Goa, India, December, 2004.

Reiff, R. (2004). *Scientists' conceptions of scientific inquiry: Revealing a private side of science*. Retrieved from Proquest Digital Dissertations. (AAT 3134038).

Reno, Ariel. (2009). Electronic Undergraduate Research Journals: A Survey of Their Characteristics. *The Eagle Feather: A Publication for Undergraduate Scholars*. 6(1-30).

Roach, M., Blackmore, P & Dempster, J. (2001) Supporting high level learning through research-based methods: A framework for course development. *Innovations in Education and Training International*, 38(4), 369-382.

Roberts, L. F., and Wassersug, R. J. (2008). Does doing scientific research in high school correlate with students staying in science? A half-century retrospective study. *Res. Sci. Educ.*

Roth, W. (1995) *Authentic school science: Knowing and learning in open-inquiry science laboratories.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Russell, C. (2010). *Development and evaluation of a research-based undergraduate laboratory curriculum*. Retrieved from ProQuest Digital Dissertations. (UMI 3418673).

Saderholm, J. (2007). *Science inquiry learning environments created by national board certified teachers*. Retrieved from Proquest Digital Dissertations.

Santos, J.R., (1999). Cronbach's Alpha: A Tool for Assessing the Reliability of Scales. *Journal of Extension,* 37(2).

Scallon, J. M. (2006). Comparative study of authentic scientific research versus guided inquiry in affecting middle school students" abilities to know and do genetics. Unpublished Master of Science Thesis, Texas A&M University, TX, USA.

Schmidt, H., Loyens, S., van Gog, T., & Paas, F. (2007). Problem-based learning is compatible with human cognitive architecture: Commentary on Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42, 91–97.

Schulz, R. (2009). Reforming Science Education: Part I. The Search for a Philosophy of Science Education. *Sci & Educ,* 18, 225–249. doi:10.1007/s11191-008-9167-1.

Schwartz, R., Lederman, N., & Crawford B. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education,* 88(4), 610-645.

Seymour, E., Hunter, A.B., Laursen, S., & Deantoni, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science Education*, 88(4), 493–534. doi: 10.1002/ sce.10131.

Silva, E. (2009) Measuring Skills for 21st-Century Learning, *Phi Delta Kappan,* 90(9), 630-634. doi: k0905sil.pdf

Sjøberg, S. (2007). Constructivism and learning. *International Encyclopaedia of Education, 3rd Ed*., Baker, E., McGaw, B. & Peterson P, (Eds). Oxford: Elsevier

Skinner, B.F. (1950) Are theories of learning necessary? *Psychological Review* 57:193-216.

Stevens, J., (2009). *Applied Multivariate Statistics for the Social Sciences, 5th Ed*., New York: Taylor and Francis Group.

Steward, J. (2007). *Research Experience and Inquiry: Uses and Effects of Authentic Envirionments in Science Education*. ProQuest Digital Dissertations. (UMI 3291067).

Sueblinvong, T., Mahaisavariya, P., and Panichkul, S. (eds). (2007). *The Ethical Guidelines for Research on Human Subjects in Thailand 2007*. Bangkok: Forum for Ethical Review Committees in Thailand.

Tashakkori, A. & Teddlie, C. (2009) *Foundations of Mixed Methods Research: Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences*. Los Angeles: Sage Publications.

Teknos. *Wikipedia.I(*2014). Retrieved from: en.wikipedia.org/wiki/Teknos.

Thiry, H., Weston, T., Laursen, S., and Hunter, B. (2012). The Benefits of Multi-Year Research Experiences: Differences in Novice and Experienced Students' Reported Gains from Undergraduate Research. *CBE—Life Sciences Education,* Vol. 11, 260–272.

Tierney, R. & Marielle Simon, M. (2004). What's still wrong with rubrics: focusing on the consistency of performance criteria across scale levels. *Practical Assessment, Research & Evaluation*, 9(2).

Trilling, B., and Fadel, C. (2009) *21st Century Skills: Learning for Life in our Times*. San Francisco, CA: Jossey-Bass.

Trumper, R. (2006). Factors Affecting Junior High School. Students' Interest in Physics. *Journal of Science Education and Technology,* 15 (1). doi: 10.1007/ s10956-006-0355-6.

Tsai, C.-C., and Tuan, H.-L. (2005). *Investigating the impact of inquiry vs. textbook instruction on 8th graders' motivation towards learning science*. Paper presented at the 5th Biannual Conference of ESERA, Barcelona, Spain.

VAMSC: Virginia Mathematics and Science Coalition (VAMSC). 2010. *Scientific Inquiry and the Nature of Science Task Force Report*. Retrieved from: www.vamsc.org/whitepapers.html.

Wang, J., Dyehouse, M., Weber, N., & Strobel, J. (2012). *Conceptualizing authenticity in engineering education: A systematic literature review.* Proceedings of the American Society for Engineering Education (ASEE) 2012 annual conference, San Antonio, TX.

Welch, A. G. (2010). Using the TOSRA to Assess High School Students Attitudes towards Science after Competing in the FIRST Robotics Competition: An Exploratory Study. *Eurasia Journal of Mathematics, Science & Technology Education*, 6(3), 187-197.

Weston, T. (2012a). *Summary of Factor Analysis for the Undergraduate Research Student: Self Report* . Obtained through Personal Communication: Hunter, A.

Weston, T., (2012b). *BIO-REU Second Year Report: Summary*. Retrieved from: bioreu.org/downloads/2011_BIO_REU_SHORT_REPORT_Appendix.pdf.

Wiggins, Grant (1990). The case for authentic assessment. *Practical Assessment, Research & Evaluation*, 2(2).

Wink, D., & Weaver, G. (2009). *Evaluation of the Center for Authentic Science Practice in Education (CASPiE) model of undergraduate research*: Commissioned Paper. Washington, DC: National Academies of Science.

Winkleby, M., Ned, J., Ahn, D., Koehler, A., Kennedy, J. (2009). Increasing Diversity in Science and Health Professions: A 21-Year Longitudinal Study Documenting College and Career Success. *J Sci Educ Technol.* 19(5), 535-545, doi: 10.1007/s10956-009-9168-0.

Wolf, S. & Fraser, B. (2008). Learning Environment, Attitudes and Achievement among Middle School Science Students Using Inquiry-based Laboratory Activities. Research on Science Education, 321–341. In Gröschner, A., Heinz, J., Lipowski, K., & Seidel, T. 2010. *S-TEAM Baseline Report and Indicators Review*. Munich: S-TEAM. Retrieved from: www.ntnu.no/wiki/download/attachments/8324761/Deliverable+9a_STEAM_wp9.pdf?version=1&modificationDate=1277292972000.

Zion, M., Cohen, S., & Amir, R. (2007). The spectrum of dynamic inquiry teaching practices. *Research in Science Education*, 37(4), 423-447.

Zion, M., Shapira, D., Slezak, M., Link, E., Bashan, N., Brumer, M., Orian, T, Nussinovitch, R., & Agrest, B. (2004). Biomind - A new biology curriculum that enables authentic inquiry learning. *Journal of Biological Education*, 38(2).

APPENDICES

APPENDIX A

Student and Parent Consent Forms

Dear Student,

I am requesting your assent to participate in my PhD research.

The research will study the effects of ISB's science courses on student attitudes and understandings of science. Your participation will involve filling out three or four surveys before the end of the school year. This will take a total of about 40 minutes. You may be asked to participate in an interview near the end of the year. Information from your ISB records will also be included in the study. My research project has been reviewed and approved by Assumption University and International School Bangkok.

I appreciate your consideration and hope that you agree to participate in this research. I would be very grateful. Should you have any questions or desire further information, please call me on 02-963-5800 or email me at jonathae@isb.ac.th.

Sincerely,
Jonathan Eales

NOTE:
- Only I will have access to your responses. Any information that is obtained in connection with this study and that can be identified with you will remain confidential.
- Participation in this study is completely voluntary. Your decision whether or not to participate will not be communicated to ISB, nor will it in any way affect you or your experience at ISB. If you agree to participate now, you are free to end participation at any time in the future.
- While no direct and immediate benefit to you is anticipated, the study is expected to indicate ways to improve the quality of science education at ISB in the future.

Please fill out the following form indicating whether you agree to participate in this research project or not.

Research Participation Consent Form

I, ____ (your name)
have read and understood the information provided and I

☐ agree to participate in this research.

☐ DO NOT agree to participate in this research.

Signed: ____

Dear Parent or Guardian:

My name is Jonathan Eales. I am a science teacher at ISB and am conducting research for my PhD Dissertation at Assumption University. I am writing to request permission for your child, an IB Science student, to participate in my research. I have already talked to your child about their participation during their IB Science class.

The research will study the effects of ISB's science courses on student attitudes and understandings of science. Your child's participation will involve filling out three or four surveys before the end of the school year. This will take a total of about 40 minutes. Your child may be asked to participate in an interview near the end of the year. Information from your child's ISB records will also be included in the study. My research project has been reviewed and approved by Assumption University and International School Bangkok.

I appreciate your consideration and hope that you agree to allow your child to participate in this research. I would be very grateful. Should you have any questions or desire further information, please call me on 02-963-5800 or email me at jonathae@isb.ac.th.

Sincerely,
Jonathan Eales

NOTE:
• Only I will have access to the information from your child. Any information that is obtained in connection with this study and that can be identified with your child will remain confidential.
• Participation in this study is completely voluntary. Your decision whether or not to allow your child to participate will not be communicated to ISB, nor will it in any way affect your child or their experience at ISB. If you and your child agree to participate now, you are free to end participation at any time in the future.
• While no direct and immediate benefit to your child is anticipated, the study is expected to indicate ways to improve the quality of science education at ISB in the future.
Please fill out the following form indicating whether you consent to your child's participation in this research project or not.

Research Participation Consent Form

I, ____ (your name)
am the parent/legal guardian of
____(student's name).
I have read and understood the information provided and

☐ grant permission for my child to participate in this research.

☐ DO NOT grant permission for my child to participate in this research.

Signed: _______________________________________

APPENDIX B

Permission for Use from Survey Instrument Authors

Permission from B. Fraser and C. Ledbetter for the use of TOSRA instrument

From: **Barry Fraser** <B.Fraser@curtin.edu.au>
Date: Sat, Feb 23, 2013 at 7:27 PM
Subject: RE: Use of TOSRA in PhD research
To: Jonathan Lee EALES <jonathae@isb.ac.th>

Jonathan
You may modify and use TOSRA. No strings attached.
As it is out of print, did you want me to send you a scanned copy of the 1981 Handbook and test?
Barry Fraser

From: **Cynthia Ledbetter** <drled87@msn.com>
Date: Tue, Feb 26, 2013 at 12:05 AM
Subject: FW: TOSRA
To: "jonathae@isb.ac.th" <jonathae@isb.ac.th>

Hi Jonathan,

You may certainly have our permission to use the TOSRA pre/post test. Do you have the scoring rubric? If not, I'll unearth it and email it to you.

As to conditions of use, please cite us in your research. And since I am still actively in the research arena, all be it in another field, I'd like to know what you find out so I'd be pleased if you'd send me a summary of your findings.

All the best,
Cynthia

Dr. Cynthia Ledbetter
Professor Emerita, Science Education
University of Texas at Dallas
DrLed87@msn.com

Permission from L. Liang for the use of SUSSI

From: **Ling Liang** <liang@lasalle.edu>
Date: Sun, Feb 24, 2013 at 7:44 AM
Subject: SUSSI
To: Jonathan Lee EALES <jonathae@isb.ac.th>
Cc: Ling Liang <liang@lasalle.edu>

Dear Jonathan,

Thanks for your interest in SUSSI. You are welcome to use/adapt the SUSSI instrument in your study. The instrument and information about the development of the instrument can be found in the Asia-Pacific Forum on Science Learning and Teaching, Volume 9, Issue 1, Article 1 (Jun., 2008) at: http://www.ied.edu.hk/apfslt/v9_issue1/liang/

The article in pdf format is attached. An application of SUSSI in an international collaborative study was published in the International Journal of Science and Mathematics Education --

Liang, L. L, Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2009). Preservice teachers' views about nature of scientific knowledge development: An international collaborative study. International Journal of Science and Mathematics Education, 7, 987-1012. (also attached)

Good luck with your research!

Sincerely,

Ling L. Liang, Ph. D.
Associate Professor, Science Education
Department of Education, La Salle University
1900 West Olney Avenue
Philadelphia, PA 19141 - 1199 USA
Tel: (215) 951-1174, Fax: (215) 951-5029

Permission from A.B. Hunter for the use of URSSA

On Wed, Feb 27, 2013 at 12:40 AM, Anne-Barrie Hunter <anne-barrie.hunter@colorado.edu> wrote:

Dear Mr. Eales,

The locked sections of URSSA are purposely locked: if you change these constructs than we cannot vouch for the validity and reliability of the instrument. And, yes, among other tests, we did conduct a confirmatory factor analysis of URSSA to help determine its reliability and validity.

You are welcome to institute your own version of the URSSA, simply cite us as your starting point, but then be very clear in stating how you have modified the instrument and, if you change the locked sections also be sure to state that these changes null any claim for the instrument's validity and reliability.

You are welcome to conduct tests on your own modified instrument to determine whether it is valid and reliable.

I wish you the best with your research.

Many thanks for your interest in our work,

Anne-Barrie Hunter

Anne-Barrie Hunter
Co-director, Ethnography & Evaluation Research (E&ER)
Center to Advance Research and Teaching in the Social Sciences (CARTSS)
University of Colorado, Boulder
580 UCB Boulder, CO 80309-0580
(Ph) 303-735-0887
(FAX) 303-492-2154
http://www.colorado.edu/eer

APPENDIX C

RESEARCH INSTRUMENTS

APPENDIX C.1

Test of Science Related Attitudes (TOSRA)

Note: Actual formatting of online survey not shown to conserve space.

Science Survey 1

Hi,
This is a survey to help me gather information about your attitudes towards science. Please give your opinion on each of the 35 statements. There are no right or wrong answers. It is important that you be as honest as possible in your answers. The survey should take less than 10 minutes.

Please understand that your participation in this survey is voluntary and be assured that your responses are confidential.

Thanks for helping me out with my research. I really appreciate it.

Mr. Eales

* Required

1 Money spent on science is well worth spending.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

2 Scientists usually like to go to their laboratories when they have a day off.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

3 I would rather find out why something happens by doing an experiment than by being told how it works.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

4 I find it boring to hear about new ideas.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

5 Science classes are fun.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

6 I would like to belong to a science club.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

7 I would dislike being a scientist.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

8 Science is man's worst enemy.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

9 Scientists are about as fit and healthy as other people.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

10 Doing experiments does not help me learn as much as finding out information from teachers.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

11 In science experiments, I like to use methods which I have not tried before.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

12 I dislike science classes.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

13 I get bored watching science programs on TV.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

14 I would like to work with people who make discoveries in science.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

15 Public money spent on science in the last few years has been used wisely.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

16 Scientists do not have enough time to spend with their families.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

17 I would rather do experiments than read about them.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

18 I am unwilling to change my ideas even when evidence shows that my ideas are faulty.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

19 School should have more science classes each week.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

20 I would like to be given a science book or a piece of scientific equipment as a present.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

21 I would dislike a job in a science laboratory.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

22 Scientific discoveries are doing more harm than good.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

23 Scientists like sports as much as other people do.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

24 I would rather agree with other people than do an experiment to find out the information for myself.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

25 In science experiments, I report unexpected results as well as expected ones.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

26 Science classes bore me.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

27 I dislike reading books about science in my leisure time.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

28 Working in a science laboratory would be an interesting way to earn a living.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

29 The government of my country should spend more money on scientific research.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

30 Scientists are less friendly than other people.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

31 I would rather do my own experiments than find out information from teachers.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

32 I dislike listening to other people's opinions.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

33 Science is one of the most interesting school subjects.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

34 I would like to do science experiments at home.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

35 A career in science would be dull and boring.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

APPENDIX C.2

Student Understanding of Science and Scientific Inquiry (SUSSI)

Note: Actual formatting of online survey not shown to conserve space.

Science Survey 2

Hi,

This is a survey to help me gather information about your understanding of the nature of science. Please give your opinion on each of the 24 statements. I would also appreciate it if you would explain your ideas more fully at the end of each page.

There are no right or wrong answers. It is important that you be as honest as possible in your answers. The survey should take less than 10 minutes. Please understand that your participation in this survey is voluntary and be assured that your responses are confidential.

Thanks for helping me out with my research. I really appreciate it.

Mr. Eales

*Required

1. Different scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

2. Different scientists' observations of the same event will be the same because scientists are objective.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

3. Different scientists' observations of the same event will be the same because observations are facts.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

4. Different scientists may make different interpretations based on the same observations.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

If you can, please explain, with examples, why you think scientists' observations and interpretations are the same OR different.

5. Scientific theories are subject to on-going testing and revision.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

6. Scientific theories may be completely replaced by new theories in light of new evidence.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

7. Scientific theories may be changed because scientists reinterpret existing observations.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

8. Scientific theories based on accurate experimentation will not be changed.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

If you can, please explain, with examples, why you think scientific theories do not change OR how (in what ways) scientific theories may be changed.

9. Scientific theories exist in the natural world and are uncovered through scientific investigations.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

10. Unlike theories, scientific laws are not subject to change.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

11. Scientific laws are theories that have been proven.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

12. Scientific theories explain scientific laws.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

If you can, please explain, with examples, the nature of and difference between scientific theories and scientific laws.

13. Scientific research is not influenced by society and culture because scientists are trained to conduct “pure”, unbiased studies.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

14. Cultural values and expectations determine what science is conducted and accepted.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

15. Cultural values and expectations determine how science is conducted and accepted.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

16. All cultures conduct scientific research the same way because science is universal and independent of society and culture.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

If you can, please explain, with examples, how society and culture affect OR do not affect scientific research.

17. Scientists use their imagination and creativity when they collect data.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

18. Scientists use their imagination and creativity when they analyze and interpret data.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

19. Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

20. Scientists do **not** use their imagination and creativity because these can interfere with objectivity.*

Strongly Agree   Agree   Not Sure   Disagree   Strongly Disagree

If you can, please explain, with examples, how and when scientists use imagination and creativity **OR** do not use imagination and creativity.

21. Scientists use different types of methods to conduct scientific investigations.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

22. Scientists follow the same step-by-step scientific method.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

23. When scientists use the scientific method correctly, their results are true and accurate.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

24. Experiments are not the only means used in the development of scientific knowledge.*

Strongly Agree Agree Not Sure Disagree Strongly Disagree

If you can, please explain, with examples, whether scientists follow a single, universal scientific method **OR** use different types of methods.

APPENDIX C.3

Rubric for Scoring SUSSI Open Responses.

Rubric for scoring SUSSI open responses*

Question	Not classifiable	Naïve view (1)	Transitional view (2)	Informed view (3)
1. With examples, explain why you think scientists' observations and interpretations are the same OR different.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Scientists' observations AND/OR interpretations are the same because scientists are objective. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientists' observations OR interpretations may be different because of their prior knowledge, personal perspective, or beliefs. OR The observations AND/OR interpretations may be different, but failed to provide reasons for justification.	Scientists' observations AND interpretations may be different because of their prior knowledge or perspectives in current science.
2. With examples, explain why you think scientific theories do not change OR how (in what way) scientific theories change.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Scientific theories do not change over time if they are based on accurate experiments or facts. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientific theories may be changed when experimental techniques improve, or new evidence is produced.	Scientific theories may also be changed when existing evidence is reinterpreted.
3. With examples, explain the nature of and difference between theories and scientific laws.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Scientific laws are more certain than theories, or theories become laws when they are proven. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientists FIND theories or laws in nature. OR The student provides valid example(s) of scientific laws and theories without further elaboration.	Scientific theories are well-substantiated explanations of natural phenomena or scientific laws. AND Both scientific laws and theories are subject to change.

Question	Not classifiable	Naïve view (1)	Transitional view (2)	Informed view (3)
4. With examples, explain how society and culture affect OR do not affect scientific research.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Science is a search for universal truth and fact which is not affected by culture and society. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientists are informed by their culture and society. Culture determines what OR how science is conducted, or accepted. OR The student simply states that science is influenced by cultural and society without further elaboration.	Scientists are informed by their culture and society. Culture determines what AND how science is conducted, or accepted.
5. With examples, explain why scientists do not use imagination and creativity OR how and when they use imagination and creativity.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Scientists do not use imagination or creativity because imagination and/or creativity are in conflict with objectivity. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientists use their imagination or creativity in SOME phases of their work, notably in designing experiments or problem solving.	Scientists use their imagination or creativity throughout their scientific investigations.
6. With examples, explain whether scientists follow a single, universal scientific method OR use different types of methods.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot b classified based on the rubric descriptions.	There is a single, universal, or step-by-step scientific method that should be used. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientists may use different methods, but their results must be confirmed by the scientific method or experiments. OR Student states that scientists use different methods without providing any justification or examples.	There is no single, universal step-by-step scientific method that all scientists follow. Scientists use a variety of valid methods (e.g., observation, mathematical deduction, speculation, library investigation, and experimentation).

*From Miller M, Montplaisir L, Offerdahl E, Cheng F-C, Ketterling G. Comparison of views of the nature of science between natural science and nonscience majors. CBE Life Sciences Educ. 2010;9:45–54. doi: 10.1187/cbe.09-05-0029.

APPENDIX C.4

Secondary Science Research Student Self-Assessment (SSRSSA)

Note: Actual formatting of online survey not shown to conserve space.

Science Survey 3

Hi,
This is a survey to help me gather information about your skills and attitudes with respect to the lab-based experimental research experiences in your science class this year. There are 8 sections with a total of 58 questions. The survey should take less than 15 minutes to complete.

Please be as precise as you can in your answers. You may choose "not applicable" for any activity you did not do or any question that does not apply to you. Remember, there are no right or wrong answers. It is important that you be as honest as possible in your answers.

There are several questions that invite an answer in your own words. Please comment candidly, bearing in mind that future students will benefit from your thoughtfulness. Remember that this is a confidential survey: you will not be able to be individually identified from any published information.

Thanks for helping me out with my research. I really appreciate it.
Mr. Eales

* Required
Section 1: Thinking and working like a scientist: Application of knowledge to experimental research work.
How much did you GAIN in the following areas as a result of your lab-based experimental research experiences in your science class this year?

1.1 Analyzing data for patterns. *

no gains   a little gain   moderate gain   good gain   great gain   not applicable

1.2 Figuring out the next step in an experimental research project. *

no gains   a little gain   moderate gain   good gain   great gain   not applicable

1.3 Problem-solving in general. *

no gains   a little gain   moderate gain   good gain   great gain   not applicable

1.4 Formulating a research question that could be answered with data. *

no gains a little gain moderate gain good gain great gain not applicable

1.5 Identifying limitations of research methods and designs. *

no gains a little gain moderate gain good gain great gain not applicable

1.6 Understanding the theory and concepts guiding your research projects. *

no gains a little gain moderate gain good gain great gain not applicable

1.7 Understanding the connections among scientific disciplines. *

no gains a little gain moderate gain good gain great gain not applicable

1.8 Understanding the relevance of the lab-based experimental research to the rest of the class content. *

no gains a little gain moderate gain good gain great gain not applicable

Section 2: Personal gains related to experimental research work.
How much did you GAIN in the following areas as a result of your lab-based experimental research experience in your science class this year?

2.1 Confidence in my ability to contribute to science. *

no gains a little gain moderate gain good gain great gain not applicable

2.2 Comfort in discussing scientific concepts with others. *

no gains a little gain moderate gain good gain great gain not applicable

2.3 Comfort in working collaboratively with others. *

no gains a little gain moderate gain good gain great gain not applicable

2.4 Confidence in my ability to do well in future science courses. *

no gains a little gain moderate gain good gain great gain not applicable

2.5 Ability to work independently. *

no gains a little gain moderate gain good gain great gain not applicable

2.6 Developing patience with the slow pace of research. *

no gains a little gain moderate gain good gain great gain not applicable

2.7 Understanding what everyday research work is like. *

no gains a little gain moderate gain good gain great gain not applicable

2.8 Taking greater care in conducting procedures in lab work. *

no gains a little gain moderate gain good gain great gain not applicable

Section 3: Gains in skills related to experimental research work.
How much did you GAIN in the following areas as a result of your lab-based experimental research experience in your science class this year?

3.1 Writing scientific reports or papers. *

no gains a little gain moderate gain good gain great gain not applicable

3.2 Making oral presentations. *

no gains a little gain moderate gain good gain great gain not applicable

3.3 Defending an argument when asked questions. *

no gains a little gain moderate gain good gain great gain not applicable

3.4 Explaining my experimental research projects to people outside my field. *

no gains a little gain moderate gain good gain great gain not applicable

3.5 Preparing a scientific poster. *

no gains a little gain moderate gain good gain great gain not applicable

3.6 Keeping a detailed lab notebook. *

no gains a little gain moderate gain good gain great gain not applicable

3.7 Conducting observations in the lab or field. *

no gains a little gain moderate gain good gain great gain not applicable

3.8 Using statistics to analyze data. *

no gains a little gain moderate gain good gain great gain not applicable

3.9 Calibrating instruments needed for measurement. *

no gains a little gain moderate gain good gain great gain not applicable

3.10 Working with computers. *

no gains a little gain moderate gain good gain great gain not applicable

3.11 Understanding journal articles. *

no gains a little gain moderate gain good gain great gain not applicable

3.12 Conducting database or internet searches. *

no gains a little gain moderate gain good gain great gain not applicable

3.13 Managing my time. *

no gains a little gain moderate gain good gain great gain not applicable

Section 4: Attitudes and behaviors related to experimental research work.
During your lab-based experimental research experience in your science class this year HOW MUCH did you…

4.1 Engage in real-world science research *

none a little some a fair amount a great deal not applicable

4.2 Feel like a scientist. *

none a little some a fair amount a great deal not applicable

4.3 Think creatively about your experimental research projects. *

none a little some a fair amount a great deal not applicable

4.4 Try out new ideas or procedures on your own. *

none a little some a fair amount a great deal not applicable

4.5 Feel responsible for your experimental research projects. *

none a little some a fair amount a great deal not applicable

4.6 Work extra hours because you were excited about the research. *

none a little some a fair amount a great deal not applicable

4.7 Interact with scientists from outside your school. *

none a little some a fair amount a great deal not applicable

4.8 Feel a part of a scientific community. *

none a little some a fair amount a great deal not applicable

Section 5: Your experience in your science class this year.
Please rate the following aspects of your experience in your science class this year:

5.1 My working relationship with my science teacher. *

Poor Fair Good Excellent not applicable

5.2 My working relationship with partners for lab-based experimental research. *

Poor Fair Good Excellent not applicable

5.3 The amount of time I spent doing meaningful research. *

Poor Fair Good Excellent not applicable

5.4 The amount of time I spent with my science teacher talking about my experimental research. *

Poor Fair Good Excellent not applicable

5.5 The advice my science teacher provided about university or careers. *

Poor Fair Good Excellent not applicable

5.6 The experimental research experience in science class overall. *

Poor Fair Good Excellent not applicable

5.7 Please comment on any of these aspects.

Section 6: Affect of your experimental research experience on your attitudes towards the future.
Rate how much you agree or disagree with the following statements. My lab-based experimental research experience in science class this year has…

6.1 increased my desire to enroll in a university program in science, engineering or medicine. *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

6.2 increased my desire to pursue a career in science, engineering, or medicine. *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

6.3 prepared me for more advanced scientific research work. *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

6.4 prepared me for more advanced scientific coursework. *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

6.5 increased my desire to apply for a position as a research assistant while at university. *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

Section 7: Motivation to participate in lab-based experimental research experiences in your science class this year?
Rate how much you agree with the following statements. I wanted to participate in the experimental research experience in my science class this year in order to…

7.1 explore my interest in science *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

7.2 gain hands-on experience in experimental scientific research *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

7.3 clarify whether I wanted to pursue a science-related career *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

7.4 have a good intellectual challenge *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

7.5 get good letters of recommendation *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

7.6 enhance my college application resume *

Strongly Agree Agree Not Sure Disagree Strongly Disagree Not Applicable

Section 8: General Comments
Please respond to the following questions in the space provided.

8.1 How did your lab-based experimental research experience in science class this year influence your thinking about future university or career plans? Please explain.

8.2 What would have made your experimental research experience in this class better?

8.3 Did you make other gains from doing experimental research in science class that we didn't mention? If so, please briefly describe these.

APPENDIX C.5

Item-Objective Congruence Validation Packet for the

Attitudes toward and Effects of Student Publishing (AESP) survey

Questionnaire Item-Objective Congruence Validation

Thank you for agreeing to help me by serving as an expert in validating the congruence between the items in my questionnaire and their objectives. I have selected you because I believe that your knowledge and experience in science and/or language pedagogy, combined with your familiarity with the science program at ISB and the *ISB Journal of Science* makes you able to accurately judge the validity of the items in this questionnaire. This packet contains:

- Instructions explaining your role & how to validate the questionnaire (pg 2),
- Item-Objective Congruence Validation form (pg 4),
- Questionnaire Validation Form (pg 8), and
- Example version of the questionnaire for reference (pg 9).

Thank you very much for helping me with this.

Thank you,

Jonathan Eales

Instructions for Expert Validation of Questionnaire
This questionnaire is intended to gather information on student attitudes toward and effects of the *ISB Journal of Science* and the possibility of publishing a paper in the Journal. The survey will be administered to IB Physics students of the classes of 2010, 2012 and 2014, and to IB HL Biology and HL Chemistry students of the class of 2014. This includes all students who have been presented with the opportunity of publishing a paper in the *ISB Journal of Science* as part of their IB Science course.

*Note that the questions in the version of the questionnaire shown on page 9 are tailored to IB Physics students. Appropriate changes in course name and Journal name will be made for the versions given to IB Biology and IB Chemistry students.

The questionnaire is divided into four sections:

- Section 1 will be completed by all students in the sample, and attempts to measure the level of desire of the students to publish a paper in the *Journal* and the reasons for that level of desire.
- Section 2 will be completed by all students, and attempts to measure the effects of the *Journal* on the student's Independent Research experience in their IB Science class. Aspects measured include the effect of the *Journal* on the motivation of the student to put forth effort on choice of Research

Question, doing background research, designing the experimental methods, conducting the experiment, analyzing results, and writing the report.
- Section 3 will be completed only by students who published a paper in the *Journal of Science* and attempts to measure the effect of publishing a paper on aspects of student abilities in scientific research, including the ability to analyze data, draw conclusions, understand other journal papers, and present findings visually and in writing. It also attempts to measure student's response to the opportunity to publish and desire to do so in the future.
- Section 4 (version a) will be completed only by students who are in university at the time of filling out the survey and did NOT publish a paper in the ISB Journal of Physics. It attempts to measure student perception of the influence of the independent research experience on students being selected to participate in research during university.
- Section 4 (version b) will be completed only by students who are in university at the time of filling out the survey and DID publish a paper in the ISB Journal of Physics. It attempts to measure student perception of the influence of the independent research experience and the publishing of a paper in the Journal on students being selected to participate in research during university.

An example version of the questionnaire, similar to how it will look on Google Forms, is attached to the end of this packet. Please take a minute to familiarize yourself with it.

To validate the questionnaire, you will need to turn to the Item-Objective Congruence (IOC) Validation form on page 4 of this packet. Please read each item and its objective, then decide if the item achieves the objective. For each Item (question), please indicate whether or not the item will validly measure the objective attribute.
- A score of "1" means you are sure that the item <u>does</u> validly measure the objective attribute.
- A score of "-1" means you are sure that the item <u>does not</u> validly measure the objective attribute.
- A score of "0" means you are <u>not sure</u> whether the item does or does not validly measure the objective attribute.

Please add comments for each item as necessary.

When you have completed the IOC, please fill in the Questionnaire Validity Approval Form on page 8. Tick "Yes" or "No" and sign the bottom of the form.

When you have finished this process, please return the packet to me.

Survey: The effect of the *ISB Journal of Science* on Student Attitudes and Motivations						
Item Objective Congruence (IOC) Validation Form						
Item No.	Item	*Objective: Attribute the Question Attempts to Measure*	Appropriateness			Comment
			1	0	-1	
Section 1: Your attitude towards publishing a paper in the ISB Journal of Physics.						
1.1	When you were enrolled in IB Physics class, how interested were you in publishing a paper in the ISB Journal of Physics?	*Level of desire to publish a paper in the Journal*				
1.2	Please outline as clearly as you can the reasons for your level of interest in publishing a paper in the ISB Journal of Physics.	*Reasons for the level of desire claimed in 1.1: Open ended*				
Section 2: Effect of the Journal of Physics on your Independent Research experience in IB Physics class.						
To what extent did the possibility of publishing a paper in the Journal of Physics …						
2.1	affect **your choice of research question** for your independent research experiments?	*Effect of Journal on effort in choosing RQ.*				
2.2	affect **your effort in finding and understanding background theory** for your experiments?	*Effect of Journal on effort in researching background theory*				
2.3	affect **your effort in designing your experimental setups and methods** for your experiments?	*Effect of Journal on effort in designing experimental methods*				
2.4	affect your **care and attention to detail when conducting** your experiments?	*Effect of Journal on care and attention to detail in conducting experiments*				
2.5	affect your **willingness to spend extra time outside of class** to ensure valid results?	*Effect of Journal on willingness to spend extra time on experiments*				
2.6	influence the **processing and analysis of data** in your experiments?	*Effect of Journal on effort in data processing and analysis*				
2.7	influence the writing of the independent research lab reports?	*Effect of Journal on effort in writing lab reports*				

Item No.	Question	Attribute the Question Attempts to Measure	Appropriateness			Comment
			1	0	-1	
2.8	Please elaborate on any of the aspects addressed in questions 2.1-2.7, or on any other aspect which you feel is important to explain further.	*Effect of Journal on any other aspects of experimental research not covered above: open ended*				
2.9	Have you changed your view of the value of the independent research program or the Journal of Physics program at any time -(version a: for current seniors) during your IB Physics course? / (version b: for 10&12 grads) since attending university?	*Identifying changes in judgment of value of the IR/JoP program.*				
2.10	If yes, please describe when and how your views changed, and the reasons for these changes.	*Identify details of and reasons for changes.*				
<u>Questions only for those who published a paper.</u>						
Section 3: Effect of publishing a paper in the Journal on scientific research skills						
3.1	Approximately how many hours total did you spend working on publishing your paper in the Journal of Physics?	*Amount of time students spent on publishing their paper.*				
To what extent did the process of publishing a paper in the Journal of Physics …						
3.2	improve your **ability to analyze experimental data**?	*Student perception of effect of publishing on ability to analyze data*				
3.3	improve your **ability to draw valid and justified conclusions** from scientific data?	*Student perception of effect of publishing on ability to draw conclusions*				
3.4	improve your **ability to present figures and graphs** well?	*Student perception of effect of publishing on ability to present information visually*				
3.5	improve your **ability to understand scientific papers** related to your research?	*Student perception of effect of publishing on ability to understand other Journal papers*				

Item No.	Question	Attribute the Question Attempts to Measure	Appropriateness			Comment
			1	0	-1	
3.6	improve **your scientific writing ability**?	*Student perception of effect of publishing on ability to write scientifically*				
3.7	affect **your desire to publish a scientific paper** in the future?	*Student perception of effect of publishing on desire to publish in future*				
3.8	Please elaborate on any of the aspects addressed in questions 3.1-3.7, or on any other aspect which you feel is important.	*Elicit further information on the aspects measured above: open-ended*				
3.9	If you can, please describe your reaction to learning that you would be invited to publish a paper in the Journal.	*Level of desire, with reasons, to publish a paper in the Journal: open-ended*				

Questions for only those who are in university at the time of taking the survey and did NOT publish a paper.

Section 4 (version a): Effect of your Independent Research experience on university research opportunities.

Item No.	Question	Attribute the Question Attempts to Measure	Appropriateness			Comment
			1	0	-1	
4.1	Have you participated in any research during your time in university?	*Participation in research at university*				
4.2	If yes, please describe what the project was and your role in the project.	*Details of participation in research at university*				
4.3	In your estimation, how much did your experience of doing independent research in IB Physics affect your being chosen to participate in this research?	*Student perception of influence of Independent Research on being chosen to participate in research at university*				
4.4	Please explain your reasons for your answer to question 4.3.	*Elicit further information on the aspect measured above*				

Item No.	Question	Attribute the Question Attempts to Measure	Appropriateness 1	0	-1	Comment
<u>Questions only for those who are in university at the time of taking the survey and DID publish a paper.</u>						
Section 4 (version b): Effect of your publishing a paper in the Journal of Physics on university research opportunities.						
4.1	Have you participated in any research during your time in university?	*Participation in research at university*				
4.2	If yes, please describe what the project was and your role in the project.	*Details of participation in research at university*				
4.3	In your estimation, how much did your experience of **doing independent research** in IB Physics affect your being chosen to participate in this research?	*Student perception of influence of Independent Research on being chosen to participate in research at university*				
4.4	In your estimation, how much did your **publishing a paper** in the Journal of Physics affect your being selected to participate in this research?	*Student perception of influence of publishing a paper on being chosen to participate in research at university*				
4.5	Please explain your reasons for your answers to question 4.3 and 4.4.	*Elicit further information on the aspects measured above*				

Assumption University Graduate School of Education
Questionnaire Validity Approval Form

Student Name: Mr. Jonathan Eales

Contact Information (phone/email): 087 518-4264 / jonathae@isb.ac.th

Dissertation Title (Working): Research and Publication in Secondary School Science: Effects and Development of a Model of Implementation

Questionnaire Title: Attitudes toward and Effect of Research and Publishing in Secondary Science (AERPSS)

Validity Approval

Do you approve the validity of this questionnaire?

☐ Yes, I, ………………………………………………………………, have read and certify the validity of this questionnaire. My comments and suggestions are noted below.

☐ No, I, ………………………………………………………………, have read and cannot certify the validity of this questionnaire. My comments and suggestions are noted below.

Comments / suggestions:

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Signature: ……………………………………………………

Date: ……………………………………………………

APPENDIX C.6

Summary of Expert Validation Results for Item-Objective Congruence

Validation for the AESP survey.

The following table shows the results of the Expert Validation of the draft AESP survey. Comments from Validators were used to refine the items. Items with an asterisk have mean validation scores below the acceptable level due to the comments of Validator F, due to a issue with phrasing of the item. These items were revised and returned to Validator F for approval. Validators' names are not shown to maintain promised confidentiality.

Item Objective Congruence (IOC) Validation Form

Item	Validator						Mean
	A	B	C	D	E	F	
1.1	1	1	1	1	0	1	0.8
1.2	1	1	0	1	1	1	0.8
2.1*	0	1	1	1	1	-1	0.5*
2.2	1	1	1	1	1	1	1.0
2.3	1	1	1	1	0	1	0.8
2.4	1	1	1	1	0	1	0.8
2.5	1	1	1	1	1	1	1.0
2.6*	1	1	1	1	0	-1	0.5*
2.7*	0	1	1	1	0	-1	0.3*
2.8	1	1	0	1	1	1	0.8
2.9	1	0	1	1	1	1	0.8
2.1	1	1	1	1	1	1	1.0
3.1	1	1	1	1	1	1	1.0
3.2	1	1	1	1	1	1	1.0
3.3	1	1	1	1	1	1	1.0
3.4	1	1	1	1	0	1	0.8
3.5	0	1	1	1	1	1	0.8
3.6	1	1	1	1	1	1	1.0
3.7	1	1	1	1	1	1	1.0
3.8	1	1	1	1	1	1	1.0
3.9*	0	1	1	1	1	-1	0.5*
4.1	1	1	1	1	1	1	1.0
4.2	1	1	1	1	1	1	1.0
4.3	1	1	1	1	1	1	1.0
4.4	1	1	1	1	1	1	1.0
4.5	1	1	1	1	1	1	1.0

APPENDIX C.7

Attitudes toward and Effects of Research and Publishing in Secondary Science (AERPSS) Survey: Final Versions

Note: Actual formatting of online survey not shown to conserve space.

Eales Science Survey 4

Hi,

This is a survey to help me gather information about your attitude towards the possibility of publishing a paper in the *ISB Journal of Science*, and on how this may have affected your efforts and gains during Independent Research in IB Physics class.

Please be as precise as you can in your answers. Remember, there are no right or wrong answers. It is important that you be as honest as possible in your answers. You may choose "not applicable" for any activity you did not do or any question that does not apply to you.

There are several questions that invite an answer in your own words. Please comment candidly, bearing in mind that future students will benefit from your thoughtfulness. Remember that this is a confidential survey: you will not be able to be individually identified from any published information.

There are 4 sections with a total of 26 questions in this survey. The survey should take only about 10 minutes, so if you could spare the time now, I would appreciate it. If not, then please complete it when you get a chance.

Thanks for helping with my research. I really appreciate it.

Mr. Eales

Please enter your First Name.

Please enter your Last (Family) Name.

Section 1: Level of Interest in publishing a paper in the *ISB Journal of Science.*

1.1 When you were enrolled in IB Physics class, how interested were you in publishing a paper in the *ISB Journal of Science*? I was…

not interested at all a little interested interested very interested extremely interested

1.2 Please outline as clearly as you can the reasons for your level of interest in publishing a paper in the ISB Journal of Science.

Section 2: Effect of the *Journal of Science* on Independent Research experience in IB Physics class.

2.1 To what extent did the possibility of publishing a paper in the *Journal of Science* affect **your effort in choosing a research question** for your independent research experiments that would lead to a publishable paper? It had…

no effect little effect a moderate effect a great effect not applicable

2.2 To what extent did the possibility of publishing a paper in the *Journal of Science* affect **your effort in finding and understanding background theory** for your experiments? It had…

no effect little effect a moderate effect a great effect not applicable

2.3 To what extent did the possibility of publishing a paper in the *Journal of Science* affect **your effort in designing your experimental setups and methods** for your experiments? It had…

no effect little effect a moderate effect a great effect not applicable

2.4 To what extent did the possibility of publishing a paper in the *Journal of Science* affect your **care and attention to detail when conducting** your experiments? It had…

no effect little effect a moderate effect a great effect not applicable

2.5 To what extent did the possibility of publishing a paper in the *Journal of Science* affect your **willingness to spend extra time outside of class** to ensure valid results? It had…

no effect little effect a moderate effect a great effect not applicable

2.6 To what extent did the possibility of publishing a paper in the *Journal of Science* influence the effort you put into the **processing and analysis of data** in your experiments? It had…

no effect little effect a moderate effect a great effect not applicable

2.7 To what extent did the possibility of publishing a paper in the *Journal of Science* influence the **effort you put into writing** the independent research lab reports? It had…

no effect little effect a moderate effect a great effect not applicable

2.8 Please elaborate on any of the aspects addressed in questions 2.1-2.7, or on any other aspect which you feel is important to explain further.

2.9 Have you changed your view of the value of the *Journal of Science* program at any time -(version a: for current seniors) during your IB Physics course? / (version b: for 10&12 grads) since attending university?

Yes No

2.10 If yes, please describe when and how your views changed, and the reasons for these changes.

Questions only for those who DID publish a paper.

Section 3: Effect of publishing a paper in the *Journal* on scientific research skills

3.1 Approximately how many hours total did you spend working on publishing your paper in the *Journal of Science*?

0-4 hours. 5-8 hours. 9-12 hours. 13-16 hours. more than 16 hours.

3.2 To what extent did the process of publishing a paper in the *Journal of Science* improve your **ability to analyze experimental data**? It had…

no effect little effect a moderate effect a great effect not applicable

3.3 To what extent did the process of publishing a paper in the *Journal of Science* improve your **ability to draw valid and justified conclusions** from scientific data? It had…

no effect little effect a moderate effect a great effect not applicable

3.4 To what extent did the process of publishing a paper in the *Journal of Science* improve your **abilities in the visual presentation (figures and graphs) of your results**? It had…

no effect little effect a moderate effect a great effect not applicable

3.5 To what extent did the process of publishing a paper in the *Journal of Science* improve your **ability to understand scientific papers** related to your research? It had…

no effect little effect a moderate effect a great effect not applicable

3.6 To what extent did the process of publishing a paper in the *Journal of Science* improve **your scientific writing ability**? It had…

no effect little effect a moderate effect a great effect not applicable

3.7 To what extent did the process of publishing a paper in the *Journal of Science* affect **your desire to publish a scientific paper** in the future? It had…

no effect little effect a moderate effect a great effect not applicable

3.8 Please elaborate on any of the aspects addressed in questions 3.1-3.7, or on any other aspect which you feel is important.

3.9 Please describe, with reasons, your reaction to learning that you would be invited to publish a paper in the *Journal*.

<u>Questions for only those who are in university at the time of taking the survey and did NOT publish a paper.</u>

Section 4 (version a): Effect of your Independent Research experience on university research opportunities.

4.1 Have you been selected to participate in any scientific research during your time in university?

Yes No

*Note: Q. 4.2-4 will only be asked if the answer to 4.1 is yes.

4.2 If yes, please describe the research project(s) and your role(s).

4.3 In your estimation, how much did your experience of doing independent research in IB Physics affect your being chosen to participate in this research? It had…

no effect little effect a moderate effect a great effect not applicable

4.4 Please explain your reasons for your answer to question 4.3.

<u>Questions for only those who are in university at the time of taking the survey and DID publish a paper.</u>

Section 4 (version b): Effect of your publishing a paper in the *Journal of Science* on university research opportunities.

4.1 Have you been selected to participate in any scientific research during your time in university?

Yes No

*Note: Q. 4.2-5 will only be asked if the answer to 4.1 is yes.

4.2 If yes, please describe the research project(s) and your role(s).

4.3 In your estimation, how much did your experience of **doing independent research** in IB Physics affect your being chosen to participate in this research? It had…

no effect little effect a moderate effect a great effect not applicable

4.4 In your estimation, how much did your **publishing a paper** in the *Journal of Science* affect your being selected to participate in this research? It had…

4.5 Please explain your reasons for your answers to question 4.3 and 4.4.

APPENDIX D

Rubric used to rate sample IRP Lab Reports on 21st Century Skills

Lab Report Rating Rubric   Report # ___

Please rate the report using the following 1-5 scale with 1 = ***not at all*** and 5 = ***a great deal.*** For each aspect, rate how much the report demonstrates that attribute on the part of the author.

1. The report demonstrates creativity in its experimental design.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

2. The report demonstrates innovation in the implementation of the design.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

3. The report demonstrates problem-solving skills in the conduct of the investigation.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

4. The report demonstrates critical thinking in its analysis and evaluation of the results.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

5. The report demonstrates effective communication appropriate to the purpose.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

6. The report demonstrates collaboration by appropriately placing itself within the context of other's research.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

7. The report demonstrates information literacy in its accessing, evaluating, and using information from a variety of sources.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

8. The report demonstrates ICT literacy if its use of technology to create, organize, and communicate information.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

9. The report demonstrates flexibility, initiative, and independence.

_____ Not at all   ____ a little   ____ some   ____ a fair amount   ____ a great deal

APPENDIX E

Trial Expansion Teacher Interview Protocol

Interview Protocol: Teacher Views on Trial Expansion of the SRPP into IB HL Biology and Chemistry

Introduction
Now that you have finished the two-year Trial Expansion of the Student Research and Publishing Program in Secondary School Science into your classes, and have thought about the school characteristics and processes necessary to implement the SRPP in a course or a school, I would like to get some feedback from you on your experience over the last two years. Please answer the following questions as fully and honestly as possible. Thanks for taking the time to do this for me.

Part 1

1. What do you feel I, as the " SRPP trainer/consultant", did well during the past two years, in my attempt to help you implement the SRPP in your course?

Answer:

2. What do you feel I, as the " RPP trainer/consultant", could have done better during the past two years, in my attempt to help you implement the SRPP in your course?

Answer:

3. What things do you feel I, as the " RPP trainer/consultant", should do differently next year to better help you implement the SRPP in your course?

Answer:

4. What do you feel I, as the " RPP trainer/consultant", did well during the past two years, in my attempt to help you establish a culture of original research and publishing among the students in your course?

Answer:

5. What do you feel I, as the " RPP trainer/consultant", could have done better during the past two years, in my attempt to help you establish a culture of original research and publishing among the students in your course?

Answer:

6. What things do you feel I, as the “ RPP trainer/consultant”, should do differently next year to better help you establish a culture of original research and publishing among the students in your course?

Answer:

Part 2

1. What do you feel you did **well** during the past two years, in your attempt to implement the SRPP in your course?

Answer:

2. What do you feel you could have done better during the past two years, in your attempt to implement the SRPP in your course?

Answer:

3. What things do you plan to do differently next year to better implement the SRPP in your course?

Answer:

4. What do you feel you did well during the past two years, in your attempt to establish a culture of original research and publishing among the students in your course?

Answer:

5. What do you feel you could have done better during the past two years, in your attempt to establish a culture of original research and publishing among the students in your course?

Answer:

6. What things do you plan to do differently next year to better establish a culture of original research and publishing among the students in your course?

Answer:

APPENDIX F

Interview Protocol for Model Development Interviews

Interview Protocol: Development of a Model for Implementation of the Student Research and Publishing Program in Secondary School Science.

Introductory Remarks

Hi, my name is Bea Toews. I have taught a range of subjects in schools around the world. I currently live in Thailand.

The topic of today's interview is the Research and Publishing program we run in IB Science here at ISB. Just to summarize, in our IB Science classes, we conduct several pieces of original independent research projects, or IRP's. After you have completed each IRP, your teacher reviews it to see if it represents work that is interesting and original, has valid results with high levels of confidence, and is suggestive of further work. If your IRP fulfills these requirements, it is submitted for peer-review and consideration for publishing in the *ISB Journal of Science*. If your IRP is selected for publishing, you go through a writing and editing process with your teacher to produce a paper on your work.

What I want to ask you about today is what you think about the Research and Publishing program here at ISB. I also want to get your opinions on the possibilities of implementing a similar program at other schools.

Before we start, let me ask you to be completely honest. I want to know what YOU think about things. There is no correct answer. Please be completely frank in your responses.

*Instructions for the Interviewer: For each question, the probes **may** be used if you feel that the interviewee has not adequately answered the question, or if additional valuable information could be derived from using them. If a different probe or follow up question seems appropriate to the situation, you may use it. There is no obligation to use the probes.*

Interview Protocols

Version S1. Student Interview 1 - Students who HAVE published

1. Let me start by asking: what you think about doing IRP's?
    a. What value do you see in them?
    b. What negatives do you see in them?

2. How do you think IRP's have affected your skills, abilities, and attitudes towards science and scientific research.
    a. In case they do not address one of these: Skills? Abilities? Attitudes?)

3. What do you think about the experience of having written a paper for the *Journal of Science*? How has it affected your skills, abilities, and attitudes towards science and scientific research?
    a. In case they do not address one of these: Skills? Abilities? Attitudes?

4. Do you think the benefits of our Research and Publishing program are worth the time and effort needed on the part of both teachers and students?
    a. Why?

5. What kind of students do you think are needed for a successful Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of students.)

6. What about the characteristics of the administration and teachers that are needed for a successful Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of admin and teachers.)

7. What about the characteristics of the curriculum and teaching methods (course content and the way the courses are taught) that are needed to successfully implement a Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of curriculum and teaching methods.)

8. What about the labs and lab equipment? What is needed in this area to successfully implement a Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of labs and lab equipment.)

9. What do you think are the overall characteristics needed by a high school in order to successfully implement a R&P program?
    a. Spend some time on this one: Prompt interviewee to give opinions on
        i. Public school/private school?
        ii. Developed/Developing country school?
        iii. National school/International school?

10. Given your experience of our Research & Publishing program do you think it would be worthwhile to implement this program in other international or national schools? Please discuss both positive and negative aspects of implementing the program in other schools.
    a. Why do you think….?/Please explain what you said about …. further.

Version S2. Student Interview 2 - Students who have NOT published

1. Let me start by asking what you think about doing IRP's?
    a. What value do you see in them?
    b. What negatives do you see in them?

2. How do you think IRP's have affected your skills, abilities, and attitudes towards science and scientific research.
    a. In case they do not address one of these: Skills? Abilities? Attitudes?)

3. Do you think the benefits of our Research and Publishing program are worth the time and effort needed on the part of both teachers and students?
    a. Why?

4. What kind of students do you think are needed for a successful Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of students.)

5. What about the characteristics of the administration and teachers that are needed for a successful Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. Details on mentioned characteristics of admin and teachers.)

6. What about the characteristics of the curriculum and teaching methods (course content and the way the courses are taught) that are needed to successfully implement a Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of curriculum and teaching methods.)

7. What about the labs and lab equipment? What is needed in this area to successfully implement a Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of labs and lab equipment.)

8. What do you think are the overall characteristics needed by a high school in order to successfully implement a Research and Publishing program?
    a. Spend some time on this one: Prompt interviewee to give opinions on
        i. Public school/private school?
        ii. Developed/Developing country school?
        iii. National school/International school?

9. Given your experience of our Research & Publishing program do you think it would be worthwhile to implement this program in other international or national schools? Please discuss both positive and negative aspects of implementing the program in other schools.
    a. Why do you think….?/Please explain what you said about …. further.

Version T. Teachers and Administrators

1. Let me start by asking: what you think about the Research and Publishing program we have here at ISB?

2. Do you think the benefits of our Research and Publishing program are worth the time and effort needed on the part of both teachers and students?
    a. Why?

3. What kind of students do you think are needed for a successful Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of students.)

4. What about the characteristics of the administration and teachers that are needed for a successful Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of admin and teachers.)

5. What about the characteristics of the curriculum that are needed to successfully implement a Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of curriculum and teaching methods.)

6. What about the labs and lab equipment? What is needed in this area to successfully implement a Research and Publishing program?
    a. Why do you think….?/Please explain what you said about …. further. (Details on mentioned characteristics of labs and lab equipment.)

7. What do you think are the overall characteristics needed by a high school in order to successfully implement a Research and Publishing program?
    a. Spend some time on this one: Prompt interviewee to give opinions on
        i. Public school/private school?
        ii. Developed/Developing country school?
        iii. National school/International school?

8. What steps would be needed to prepare teachers to implement a Research and Publishing program?

9. What about administrators, what would they need to do to prepare for the implementation of a Research and Publishing program?

10. How would you go about establishing the *Journal of Science*?

11. Once you had a Journal set up, and had prepared the teachers and administrators, how would you prepare the students and parents for implementing a Research and Publishing program

12. Once you were ready to begin implementing a Research and Publishing program, how would you introduce it: One subject first, then expand, or all subjects at once?

13. What time frame do you think is reasonable for establishing a Research and Publishing program in a High School? 1 year? 2 years? 4 years?
    a. Why do you say that? Could you please explain your thinking on that?

14. Given your experience of our Research & Publishing program do you think it would be worthwhile to implement this program in other schools? Please discuss both positive and negative aspects of implementing the program in other schools.
    a. Why do you think….?/Please explain what you said about …. further.

APPENDIX G

Results of first phase of Inductive Thematic Analysis of Model Development

Interviews – Coded Interviews with Initial Theme Identification

The coded interviews are organized by interview question into tables. Each question is identified by which group(s) it was asked of. Questions are identified by the version of the interview protocol it was included in and its question number in that version. There were three versions of the interview protocol: S1 for students who *did* publish a paper in the *JoS*, S2 for students who did *not* publish a paper in the *JoS*, and T for teachers and administrator. For example, Question S2Q3 would be the third question in the interview protocol for students who did not publish a paper.

Interviewees are identified by the protocol version used along with an identifying number to maintain promised confidentiality. Students are identified by S, Teachers by T, Administrators by A, and the Co-Founder of the *JoS* by CF.

Question: (S1Q1, S2Q1) What do you think about doing IRP's?

	Key Findings and Themes				
	Skills developed	**Self-determined**	**Overall positive**	**Creative, original thought**	**Excessive time requirements**
S1-1	develop skill, writings				too long and complicated
S1-2	hands-on, solving problems, scientists perspective	self-determined		come up with original ideas, think creatively	IB style reports too complicated, not like scientific papers
S1-3	learned research process	independence		create new knowledge, original thought	
S2-1		self-determined	really good	explore new aspects	lot of time
S2-2	help understand things more fully, apply theory		fun	original thought leading to disco-vering new knowledge	planning time important
S2-3	in-depth understanding of specific topic, writing skills	independent, individual, intrinsic	helps at uni, motivated interest in science, sense of fulfillment		

Question: (S1Q2, S2Q2) How do you think IRP's have affected your skills, abilities, and attitudes towards science and scientific research.

	Key Findings and Themes				
	Improved attitude towards science	**Data-analysis & evaluation skills**	**Writing skills**	**Time management**	**Think like a scientist**
S1-1	improved attitude towards science	understanding vs memorizing, development of understanding, evaluating weaknesses in data	writing skills		understand process of science
S1-2	valuable	rewarding to succeed in discovering something original	precision in language, improve writing	independent discovery and conduct of experimental process	understanding theory
S1-3	didn't realize gains being made at the time	analyze	concise expression	perseverance, follow own interests	think like scientists
S2-1	strengthens existing attitudes towards science		writing	time management and organization	
S2-2	confirm attitudes towards science	data-analysis skills, evaluating uncertainties	ability to use scientific language		
S2-3		analyze data	writing, scientific language	time management and organization	think like a scientist

Question: (S1Q3) What do you think about the experience of having written a paper for the *Journal of Science*? How has it affected your skills, abilities, and attitudes towards science and scientific research?

	Key Findings and Themes					
	Part of scientific community	**Added knowledge to current body**	**Increased understanding of and abilities in various aspects of scientific process**			
S1-1	felt part of scientific community	feel proud to publish	understand scientific process	analyze other's work	understanding scientific language	scientific writing, concise writing
S1-2	new perspective toward science, authentically participate in the scientific process	developing and adding knowledge	understanding the application of theory to a situation	linking different situations with similar theory	understanding importance of blind review to scientific integrity	
S1-3	part of scientific community	added knowledge to current body	process of experimental science	process of scientific publishing		scientific writing, concise writing

Question: (TQ1) What do you think about the research and publishing program we have here at ISB?

	Key Findings and Themes			
	Very valuable opportunity	**Authentic science engaging learners**	**Challenge: Benefits all students**	**Misc. benefits / Concerns**
CF	unique in the world			audacious, risky, splendid
T1	very valuable	real-world connection, kids see relevance of labs and writing	possibility of publishing interests and inspires students to push themselves	raises level of writing of all students,
T2	extremely valuable, unique opportunity	real-world learning, gives connection to real science	challenge, benefit to all students: interested in challenging selves	gain confidence to participate in undergrad research, higher-level writing
T3	good thing, unique opportunity	experience with scientific research	lofty goal to shoot for, instills perseverance and dedication, doesn't have to be high-level research (entry level), all kids (not just smartest) can do it.	singles out special kids who have achieved this, Good in that kids are selected. Nice that publishing part piggy-backs onto course-based IRP, Good in that it is optional
T4		real, genuine science		motivating, interesting, impressive to Uni's
A1		results in interesting, engaging learning, opportunities to have a publication that the scientific community can access,	pushes kids to extend their learning, creates a culture of pushing yourself, encourages rigor. extends benefits to all students, not just those who end up publishing	benefits individuals who publish, kids are affirmed and encouraged, feel special
A2	good thing as it inspires excitement in kids	excitement of discovery, opportunity to be published and share findings with world	opportunity to experience their passion for science, publishing complements the IRP program	would be good in all subjects, possible negatives with students who cannot manage time to do it. Can distract from other responsibilities
A3	fantastic		tremendous opportunity for students to develop their learning further, requires high-level capacity	concern about disappointment for kids who want to publish and cannot

Question: (S1Q4, S2Q3, TQ2) Do you think the benefits of our research and publishing program are worth the time and effort needed on the part of both teachers and students?

	Key Findings and Themes	
	Yes/No/Depends	**Experiencing the scientific R&P process in HS is very valuable, leads to opportunities in future.**
CF	In terms of IB scores, not worth it, In terms of students careers at Uni, very high value. Of critical importance for best students. Teachers: richer, more exciting professional life.	Students who publish are getting opportunities to participate in research in Uni much earlier than usual.
T1	Absolutely worth the time and effort (for students) "If our goal is to make it relevant and our goal is to get them to be confident at a high level of scientific work and writing, then yes it is definitely worth it." can see change in students, particularly those who publish	links classroom to greater scientific community
T2	worthwhile. "If you are passionate about your discipline, about the experimental sciences, and if you're passionate about education, this affords you opportunities, real connections, real possibilities for your students that you don't have otherwise."	so valuable because it is genuinely part of the scientific community. its what science looks like outside of school
T3	Students: worthwhile and worth time: can do something worthwhile and do it to a high standard, Teachers: worthwhile because its really unique	
T4	in terms of exams I prefer them to do practice questions, in terms of real science and learning, maybe I would prefer them to do the paper.", Not sure if it is worth time and effort. for certain students, it might be worth it.	
A1	Yes, worth it., Students: even though no grades attached, obvious intrinsic benefits learning-wise, also letters of recommendation, college apps,	
A2	not suited for everyone, but valuable for those who want it, exciting for kids to be published	
A3		

Question: (S1Q4, S2Q3, TQ2) Do you think the benefits our research and publishing program are worth the time and effort needed on the part of both teachers and students?

	Key Findings and Themes		
	Yes/No/Depends	**Possibility of publishing motivates students to challenge themselves. Very rewarding for those who are published.**	**Experiencing the scientific R&P process in HS is very valuable, leads to opportunities in future.**
S1-1	yes	Idea of publishing is motivating, being published is the reward	
S1-2			
S1-3	Absolutely worth the time and effort (for students), For Teachers: rewarding, if they have a heart for it	publishing is the way we share the new learning: absolutely worth it for the students	Learning to research is critical. research is the way you learn to think, learn new things about science, gives students experience of how scientific research is done while still in HS
S2-1	Yes	idea of possibility of publishing inspires us to push ourselves , knowing that our research might be publishable felt really good.	
S2-2	Of course its worth it	publishing is getting your name out there, possibility of publishing is exciting	good for college applications, good for future in college. differentiates you from others
S2-3	Research Program: good to have it, Publ. Program: strongly recommend, Teachers: positive because helping students who want to excel	Publ: enhancement of personal achievement, only for those who want it. They put in time and effort and they benefit-win-win	Pos: raises overall standard of effort in the class, as there is this opportunity to publish.

Question: (S1Q5, S2Q4, TQ3) What kind of students do you think are needed for a successful Research and Publishing program?

	Key Findings and Themes				
	Characteristics		Requirements		Misc.
	motivation, commitment, persistence	curious, creative, passionate	Organization, time-management	Minimum level of ability and motivation needed	
CF	Motivated		time	sufficiently competent	
T1		creativity			must find unique and original topic
T2	intrinsic motivation, enjoy challenging self		must have time to commit	don't need to be most academically gifted	
T3	intrinsically motivated, engaged	passionate about science		don't have to be super smart	concerned about integrity of data
T4	Motivated		time management	high attention to detail, very bright in that area	
A1	Confident				willing to take risks
A2	inspired by what they're doing	passionate about subject	well-organized	certain level of academic ability	
A3			time-mangmnt		
S1-1	wanting to find an answer by ourselves	passionate, creative, interested	time to be creative, think new things		apply real-life situations to science
S1-2	same as S1-1				
S1-3	perseverance, responsibility	intellectually curious		anyone can do it, shouldn't be selected for best students	writing ability, requires teacher guidance
S2-1	commitment, desire to achieve in science	passion			
S2-2		creative, investigating a new idea	good time management		
S2-3	motivation: can be created by a good tacher.	interest	Well-organized	not for every student, not every student has the ability to do this	

Question: (S1Q6, S2Q5, TQ4) What about the characteristics of the administration and teachers that are needed for a successful Research and Publishing program?

	Key Findings and Themes				
	Teacher			**Admin**	
	Competent teacher, knowledgeable in discipline	**Understand process of scientific research**	**Passionate about program**	**Supportive of program/see value in program**	**No need for involvement**
CF	capable, educated in their fields	practitioners of their discipline: writers of material	motivated	appoint suitable staff, funding for labs	admin irrelevant to publishing aspect, curriculum that can accommodate IRP
T1	supportive to students and colleagues		passionate about program	see value in program, act in ways that shows the school values it.	
T2	knowledgeable in their discipline	exposure to research and publishing	must be able to commit time to program	funding support for program	
T3		experienced in editing process		nice if they are supportive	Don't need support, can be done without admin
T4	knowledgeable in discipline		dedicated to program, enthusiastic, motivated		No evidence admin has offered any tangible support
A1	knowledgeable, competent enough to handle all other duties plus this	inquirer themselves			no need to be directly involved
A2	able to inspire, engage kids , able to select students to participate appropriately		passionate, enthusiastic	understand the value of the program, able to judge the approp-riateness of the program within context of school.	
A3			committed		allow teachers the freedom to get on with things

Question: (S1Q6, S2Q5, TQ4) What about the characteristics of the administration and teachers that are needed for a successful Research and Publishing program?

	Key Findings and Themes		
	Teacher		**Admin**
	competent teacher, knowledgeable in discipline	**passionate about program, supportive of the program**	
S1-1	Good at subject, likes subject		
S1-2	competent, good classroom atmosphere		
S1-3	trained in field, understand how research is conducted	need to care about program, willing to commit time and effort to the student, mentoring the student through the research process	has experience as teacher, no need to be scientifically literate, open-minded
S2-1	knows what they're talking about	supportive	
S2-2	has respect of students	passionate, supportive	provide funding
S2-3	knowledgeable, interesting teachers	supportive	set up recognitions/ rewards for program to increase motivation. ensure counselors push program to appropriate students

Question: (S1Q7, S2Q6, TQ5) What about the characteristics of the curriculum and teaching methods (course content and the way the courses are taught) that are needed to successfully implement a Research and Publishing program?

	Key Findings and Themes		
	Scaffolded series of labs to teach skills of open inquiry, leading up to IRPs, IRP's starting in Gr 9	**Engaging and varied teaching methods**	**Requires both lab work and content**
CF			Same as T1
T1	Inquiry based labs, not cookbook labs, focus on IR in grades 9 and 10		Curriculum that requires both lab work and content
T2			Same as T1
T3			Same as T1
T4			
A1	IRP in grade 9		Same as T1, IB most amenable for this program
A2			
A3	Curriculum must include inquiry		
S1-1	lots of experiments	Good with analogies, Lots of visuals	
S1-2		animations/simulation, organized, has a teaching plan	
S1-3		not plug and chug	Keep students focused on purpose of learning the theory…doing it to be able to conduct research
S2-1	Lots of learning labs before IRP's, exemplars/resources of what kids have done in past.		
S2-2	lots of experiments, Learning Labs before IRP's	demonstrations	
S2-3			Curriculum can be constraining, Curriculum used must allow program implementation.
S2-3		engaging teaching to create interest. Hard to do this, its what makes a good teacher	Curriculum: balance between lab work and content

Question: (S1Q8, S2Q7, TQ6) What about the labs and lab equipment? What is needed in this area to successfully implement a Research and Publishing program?

	Key Findings and Themes	
	Standard labs and equipment, including computers and probes, of developed country HS is adequate for the RPP program	**Variety of equipment, ability to source on short notice**
CF	computers with graphing software and word processing. Makes the research process quick enough to be able to do in a school.	
T1	Nice, but not necessary, to have each teacher with own lab	a variety of equipment, a couple pieces of each
T2	There is a minimum threshold of equipment, but standard lab equipment developed country HS Lab is adequate	
T3		
T4	Every teacher must have own lab, organized equipment	
A1	standard lab equipment developed country HS Lab is adequate, Nice, but not necessary, to have each teacher with own lab	
A2		variety in the equipment, systems in place to allow students to order equipment, ability to order materials in short time
A3		
S1-1	Basic equipment okay allows to learn creativity and the scientific process, no need for advanced equipment	
S1-2		
S1-3	There is a minimum threshold of equipment, but standard lab equipment developed country HS Lab is adequate, advanced equipment not necessary to learn skills	Ability to source unique stuff for IRPs
S2-1	Reliable equipment	List of available equipment for students
S2-2		List of available equipment for students
S2-3	shop for building apparatus would be nice	

Question: (S1Q9, S2Q8, TQ7) What do you think are the overall characteristics needed by a high school in order to successfully implement a research and publishing program? Could be done by private/public? Nat'l/Int'l? Developed/Developing Country?

	Key Findings and Themes			
	Type of School (private/public? Nat'l/Int'l? Developed/Developing Country?)	**Enthusiastic teacher with flexibility to get it started and students with motivation and interest**	**School and curriculum need to be flexible, to allow the teacher the freedom to innovate with independence, creativity.**	**adequate resources**
T1		need passionate teacher(s) to drive the program		
T2	small school might need external support		curriculum that allows the flexibility to do the program	adequate funding
T3	Either possible, but easier in private: usually better funding. Other categories, doesn't matter.		curriculum with time in it to focus on experimental skills, focus on process, not content	
T4		staff with expertise		facilities
CF	doesn't matter	have exceptional teachers, Need enthusiastic teacher with room to get it started	School need to be slightly disorganized, to allow the teacher the freedom to innovate, independence, creativity. allow flexibility in the school	
A1	easier to do in private school, Some Nat'l schools have a lot of oversight, that would be an issue	Need teachers with a passion/ drive for the program	teachers with lower teaching loads, so have time to innovate and think.	
A2	Developing country schools could do it, but much more challenging	teacher goodwill, wanting to support students passion	flexibility, open-mindedness, safe culture to take risks	capacity to run the program, supportive admin
A3			flexibility of system, Light enough teaching load with small enough classes	need minimum amount of funding,

Question: (S1Q9, S2Q8, TQ7) What do you think are the overall characteristics needed by a high school in order to successfully implement a research and publishing program? Could be done by private/public? Nat'l/Int'l? Developed/Developing Country? (S1Q9, S2Q8, TQ7)

	Key Findings and Themes	
	Type of School	**Misc.**
S1-1	Int'l: Many nations have educ cultures based on content and memorization. They could not do this. Also as this program does not yield direct, immediate, quantifiable results, it is not highly valued.	
S1-2		Supportive faculty, Interest level of school population. Culture that encourages program, adequate equipment and capital
S1-3	Private better: fewer people making decisions. In public can be done only if have support of admin, other categories doesn't matter. big is better, but small isn't impossible. Fewer students interested in publishing, less money to invest in equipment.	
S2-1		
S2-2	private schools tend to have more funding. big better: more people to exchange ideas with	background doesn't matter, just personal interest and curiosity in sciences
S2-3	both would be able to implement, but easier at private: better funding, better teachers, Other categories, doesn't matter, depends on quality of teachers and available of basic levels of funding	better teachers, better resources make it easier, but still possible without that, if have students who can and want to do.

Question: (TQ8) What steps would be needed to prepare teachers to implement a Research and Publishing program?

	Key Findings and Themes			
	Strong in inquiry teaching, Passionate about the program. Well-implemented independent research program.	**Training for the skill set involved in the program**	**Long-term expert consultant to guide the process.**	**A vision, an exemplar modeling the program**
CF	teachers who are culturally scientists. teachers who are brash enough to do this			
T1	Strong in inquiry teaching. well-implemented independent research program.			
T2	Would need to have teachers expert in inquiry teaching first, and if not expert in that, would have to become so before thinking about implementing the Publ. aspect. Must master Rsrch. before Publ. Convince teachers of value of program	training in criteria for publishable paper		
T3	teachers expert in inquiry and experimental skills. Teachers with an IR program in their courses.	teachers must understand the selection criteria and that not everyone who wants to will be able to publish.		
T4			Long-term expert consultant to guide the process.	
A1		training for the skill set involved in the program	training by an expert teacher experienced in the program	a vision, an exemplar modeling the program
A2		training to establish publishing systems and criteria	need consultant to help with implementation	
A3	teachers who are passionate about the program			exemplars of the program

Question: (TQ9) What about administrators, what would they need to do to prepare for the implementation of a Research and Publishing program?

	Key Findings and Themes		
	Pick staff that have the capacity, passion, then give them the freedom to operate	**Support the program with resources. Support the implementing teachers.**	**Ensure a clear understanding of program by teachers, students, and parents**
CF	Appoint the right staff. Critical. Then step back and let them run it. allow the freedom for the program to operate	support the program with resources. support the teachers doing the implementing	
T1	find/convince one teacher who is passionate about the program		See evidence of value and success of program
T2	Find teachers with time and desire to do program		Be able to show parents and teachers that everyone benefits from program, not just those who publish, Make sure everyone understands that not all students will be able to publish
T3			Be made aware of it
T4	Look for a very committed teacher	Establish a stipend for the program, Be committed to the program, See the value in the program	
A1	Pick staff that have the capacity, passion, ability to sell the vision, then give them the freedom to operate	ensure adequate funding	
A2		clear the road of things that will challenge and block teachers as they implement the program	ensure a clear understanding of the program
A3		Possibly establish ways of recognizing achievement in the program. open communication to be able to support	

Question: (TQ10) How would you go about establishing the *Journal of Science*?

	Key Findings and Themes			
	Determine if school has the capacity and need for program	**Need teacher with passion and ability to implement.**	**External reviewer who is knowledgeable and respected**	**Exemplar/ training in how to establish Journal and write papers**
CF		Find right teacher and get on the staff, Ensure reasonable teaching load for teacher leader	Find external reviewer who is knowledgeable and respected	
T1	Assume well-established inquiry-based/Ind. research program			Would need training in how to actually establish the Journal
T2		Need teacher with passion and ability to do it	Need Reviewers	
T3		Start small		Need exemplar of existing Journal, Transforming lab report into paper is the hardest part
T4		Admin: get science staff on board, Teacher: get admin support, only proceed after admin support ensured		
A1	Determine if the school has capacity and need for program, and the learning needs that are being met by the program			
A2	Make sure it is right time and environment in school: kids are right, environment is supportive(curriculum allows it)	Find right people: passionate scientists, a gem, Sometimes might have to plant the seed of the idea and wait some time for it to sprout		
A3	Make sure the school has the capacity, Nature of the teachers in the dept	Light enough teaching load with small enough classes, admin encourage, and support, Compensation		

Question: (TQ11) Once you had a Journal set up, and had prepared the teachers and administrators, how would you prepare the students and parents for implementing a Research and Publishing program?

	Key Findings and Themes		
	Program Presentation: All or Few?	**Program Launch: Loud or Quiet?**	**Misc**
CF	Parents don't need to be involved by you until their student has published	start quietly, no formal program, start website and post edited student work on it	Need models for students to work from
T1	Offer evidence of success in other schools, with research on effects	Publicize the program on website	
T2	share exemplars with parents, explain program		
T3		Formal launch to explain to student body the program and its advantages, Not something that's just emerging in the wings	
T4	Present program and its advantages to students and parents. Present individually to students you judge are capable and interested	Do not present to entire student/parent body	
A1			Must be driven by teachers. Admin role is to support the teachers doing the implementing
A2	Should present program to all students, Work with students who show interest in publishing to get info to their parents	Don't need much publicity to parents/community.	
A3		allow to grow naturally	Make it clear that it is not a requirement

Question: (TQ12) Once you were ready to begin implementing a Research and Publishing program, how would you introduce it: One subject first, then expand, or all subjects at once?

	Key Findings and Themes		
	One subject first	**All subjects at once**	**It depends**
CF	one teacher, one subject, then expand later: If have failures, can just pick yourself up, learn from the failures, and try again. If have big fanfare and fully launch and public implementation, then failure will be very public, and possibly fatal to the program		
T1			Either, depends on teachers involved
T2		If have teachers interested from all subjects, go ahead and start all at once	Depends on capacities of group.
T3		Should start all at once, need all teachers on board: Don't want bio kids jealous of physics kids who can publish	
T4			Depends on Admin. If they support dept. to get teachers from all subjects on board, then start all at once
A1	Given that it's mostly likely to be driven by a single teacher, then start it in whatever subjects the founding teacher(s) are in.		
A2			
A3			

Question: (TQ13) What timeframe do you think is reasonable for establishing a research and publishing program in a high school?

	Key Findings and Themes		
	If established Inquiry program, then min 2 years to establish the publishing aspect. 1 year to get things organized.	**1 year to get students involved, work out procedures**	**Starting from 3rd year, looking to publish first papers. Could be longer depending on school culture.**
CF	To establish Research aspect, will take many years, need stable faculty, low turnover. You are changing culture and it will take many years.		
T1	Given well-established IRP program from grade 9, could establish in 1 year.		If no Research program, then 5 years plus
T2	Given well-established IRP program from grade 9, would take min 2 years.	Closely working with outside expert would reduce the time.	
T3	If have established Inquiry program, then min 2 years to establish the publishing aspect.	Year 1 to talk to teachers, admin, get on board, tweak curriculum if needed.	Year 2 to work with students, getting buy-in and involvement. Could be longer depending on school culture
T4	1 year to get things organized.	1 year to get students involved, work out procedures, look at reactions from those involved.	Starting from 3rd year, looking to publish first papers.
A1	Should be little resistance to initiating the program, as it is voluntary with zero negative consequences. Easier to start as affiliate/part of existing program. Should be able to do within 2 years.		
A2			5 years for the program to be embedded. Rushing, might end up losing it. Timing depends on type of school, size of school, current culture of school.
A3			

Question: (S1Q10, S2Q9, T14) Given your experience of our Research & Publishing program do you think it would be worthwhile to implement this program in other international or national schools?

	Key Findings and Themes		
	Definitely, for the right schools with the right kids	**Program gives experience of what its like participate in scientific process.**	**Pros/Cons of program**
CF	Would like to see all schools do this in some way.	Would like to see some sort of publishing going on in all subjects.	
T1	it is excellent, Not possible if curriculum doesn't support or if admin doesn't support	bridges school science with real science	Pro: moves school forward
T2			Con: teachers have no time
T3	Absolutely, 100%		Pro: biggest benefit is for the kids, especially top students, rewarding experience for the teacher to give this type of opportunity to their students
T4	For the right schools with the right kids, yes, Not suitable for all schools		
A1	Absolutely the right thing to do, must have the preconditions before you implement		
A2	Yes, valuable program, but must have right environment, not for every school/student, depends on curriculum		
A3			

Question: (S1Q10, S2Q9, T14) Given your experience of our Research & Publishing program do you think it would be worthwhile to implement this program in other international or national schools?

	Key Findings and Themes		
	Definitely, for the right schools with the right kids	**Program gives experience of what its like participate in scientific process.**	**Pros/Cons of program**
S1-1	Definitely	"I honestly didn't think that I liked science very much before I started doing these intense research projects, and it helped me find my passion and that's an important part."	Pro: Creativity, Helps students learn whether they like science or not
S1-2	They should	gives experience in doing science, which is generally lacking at the HS level	Con: Time demands, if you're too busy
S1-3		program gives experience of what its like to do research	No real negatives
S2-1		really good opportunity for kids wanting to pursue a future in science	Pro: makes you stand out if you publish. gives more opportunities later on
S2-2	Yes		Pro: student gets scientific recognition for publishing, benefits school reputation
S2-3	Definitely for most schools, Not for non-science focused schools	makes students more scientifically involved at a younger age	Pro: Better writers, better researchers, non-required, good opportunity, definitely enhance student's experience. Con: Time demands, resulting in putting less effort into our other subjects

APPENDIX H

MODEL VALIDATION DOCUMENTS

APPENDIX H.1

Draft Model for Implementation of the SRPP – Validation Packet

Validation of a Model for Implementation of the Student Research and Publishing Program in Secondary School Science

Note to Validators:
As part of my research, I need to establish the validity of the Model for Implementation that I have developed as part of my dissertation. The Model for Implementation that follows in part 3 of this document describes the process that a secondary school should go through in order to establish a successful Student Research and Publishing Program (SRPP).

I have asked you to act as a validator of the Model due to your expertise in a relevant area of education. Your role in this is to read through the following model and consider, based on your experience and expertise, if the proposed model is valid, in other words, if using the model will result in the successful implementation of an SRPP in a school. There are a series of questions to help guide you in your assessment, and a Validation Form for you to complete at the end. While reading the Model for Implementation, please assess the validity of the Model in terms of the following criteria:

1. ***Precision**: The elements of the model are clearly described and precisely defined. There is no ambiguity in any of the parts of the model.*
2. ***Sufficiency**: The model as a whole is sufficient to bring about the expected result; a successful Research and Publishing Program. There are no necessary parts or steps that are missing from the Model.*
3. ***Feasibility**: All elements of the Model can be feasibly implemented by the relevant personnel in real situations.*
4. ***Effectiveness**: There is a reasonable level of confidence that correctly following the model will achieve the expected results; a successful Research and Publishing Program.*

At the end is a form asking you to rate the Model on each of the four aspects above, with space for any comments or suggestions on each aspect. (Validator comments and suggestions will be incorporated, as appropriate, into a revised final version of the Model.) Finally, you are asked to approve the overall validity of the Model as a whole.

Model for Implementation of a Student Research and Publishing Program in Secondary School Science

Introduction

The Student Research and Publishing Program in Secondary School Science has been shown to yield positive student results over a range of learning outcomes. It is expected that schools that are made aware of this program may be interested in implementing it. The following is a model, or suggested series of steps, that can be followed by secondary schools during implementation of a Research and Publishing Program in Science. It is expected that using this Model for Implementation at a school will result in a successfully established Student Research and Publishing Program in Secondary School Science at that school. The Model is based on data gathered from students, teachers, reviewers, and administrators who have been involved in the successful SRPP at ISB.

Phase 1: Determining the suitability of the Student Research and Publishing Program for a school

The first step in the implementation process is to verify the suitability of the SRPP for a particular school. It is clear that this program is not suitable for all schools, and that not all schools have the capacity to successfully implement it. It is thus necessary for the school to conduct a study to determine whether the SRPP could be successfully implemented. The following are the characteristics of a school that is likely to benefit from an SRPP and at which implementation has a higher chance of success.

School Structure

- Administrative Flexibility: The administrative structure of the school must be quite flexible. Schools which allow teachers and students the freedom to experiment and innovate are more likely to succeed. Schools which are rigid in the curricular and program requirements, which have tightly prescribed programs, and at which new programs require approval from many levels of the organization are unlikely to succeed in, or benefit from, implementation of the SRPP.
- Curriculum: The curriculum at the school must be one that allows for significant time to be devoted to lab work. Open-inquiry must be a regular feature of the science courses at the school.
- Class Size: Class sizes at the school must be small enough so that teachers have the time to institute Independent Research Projects as part of the curricular program. In a class of 40 students it is impossible to run IRP's, and the time required to grade the reports would be untenable for the teacher. Class sizes of 25 or less are needed for successful implementation of the SRPP.

Physical and Capital Resources

- Laboratories: While having one lab for each teacher is an advantage, the SRPP can be implemented in schools where teachers share lab rooms.
- Lab Equipment: Any school that has science labs furnished to a standard typical of schools in developed countries, with computers and peripherals for data collection, is capable of implementing the SRPP. The ability to

source a variety of non-typical equipment on short notice is an advantage, as that allows students to follow their interests when conducting Independent Research Projects.

- Funding: The school must have the funding to support the SRPP. While not excessive, funding is needed for teacher stipends and for the purchase of a variety of equipment for IRP's.

Student, Teacher and Administrator Characteristics

- Students: There must be a significant proportion of students at the school who value education and are interested in pursuing science as a career. It is not necessary to be a selective school with super-smart students. Students who are motivated to excel and are committed to science are all that is needed to be able to implement a successful SRPP.
- Teachers: The school must have teachers who are well-trained in their disciplines. They must be skilled in teaching open-inquiry in science and familiar with the process of scientific research. Finally they must be passionate about teaching science, able to inspire and engage their students.
- Administrators: Administrators at the school should understand the SRPP and see the value in it, commit adequate resources to supporting it, and, if necessary, work to clear any institutional road-blocks to implementing the program. Given that the SRPP is primarily teacher-driven, there is little requirement for direct administrator action beyond this.

If conditions at the school are in reasonably close alignment with those outlined above, it can be concluded that the Student Research and Publishing Program would be highly beneficial to the students and its implementation would stand a high chance of success.

Phase 2: Preparation for Implementation of the Student Research and Publishing Program

Note: For this part of the Model, it will assumed that the school meets all the criteria outlined in Phase 1. If a school is lacking in any specific area, it is recommended that the issue be addressed before implementation of the SRPP. The details of the remediation needed in any particular area are beyond the scope of this Model and will not be addressed here.

The preparation necessary for implementation of the SRPP varies with the school. Each school will find itself in a unique situation, so each school will have a unique path to implementation of the SRPP. However, certain general areas of preparation can be identified.

- **Identifying the lead teacher(s) for implementation of the SRPP**
  This can occur in one of two ways. If the administration of the school is the driving force behind implementation, they need to approach a teacher or group of teachers that meet the criteria with a proposal to implement the SRPP and obtain their commitment to the program. This commitment may take some time to obtain, depending on the school and the teachers. It is also possible for implementation of the SRPP at a school to be teacher-driven. In this case one

or more teachers will see the value of the SRPP and commit to implementing the program. They would need to approach the administration to obtain their commitment to support the program as necessary. This is probably the most difficult step in the whole process. Given that the drivers of this program are the teachers, it is impossible to implement without the leadership of a teacher who is competent and committed.

- **Training the lead teacher(s)**
  Implementation of the SRPP will be most efficient and have the highest chance of success if a consultant with experience in running a successful program is engaged to train the lead teacher(s). The lead teacher(s) will need to understand the benefits of the program, develop an in-depth understanding of the details of the program, and develop expertise in the skill set needed to implement and run the program. The use of an exemplar program, with exemplars of all the components and processes involved in the SRPP would be beneficial in this process. It is expected that much of the training can be done on-line or via electronic communication.

- **Preparing the curricular research program**
  It is essential that the philosophy and organization of the science program be aligned with the SRPP. Each course must be (re-)designed to focus on the process of science as a whole, with students reminded regularly that the mastery of the course content is the foundation for the knowledge creation and publishing processes. The lab component of each course must prepare the student for the culminating Independent Research Project, in which the students design and conduct original research to create new knowledge, with the view to potentially publishing their results. The need for this step will depend on the school, with some schools having Independent Research programs already established only needing minor tweaks, while schools without a well-established IRP program will need more significant modifications to their programs.

- **Establishing appropriate teacher compensation and student recognition**
  A system offering compensation of some form for the teachers involved, whether it be financial or time-based, must be established in preparation for implementation of the SRPP. It is recommended that recognition protocols for students who publish their work be considered. The ways in which students are recognized will vary according to the school, but may take the form of recognition at assemblies or in school publications, or the issuing of certificates of achievement.

Phase 3: Implementation of the Student Research and Publishing Program
Once the lead teacher(s) have been identified and trained, and the curricular research program has been designed, it is time to begin implementation of the Student Research and Publishing Program.

- **Research**
  Implementation of the SRPP should start with implementation of the research part of the program, if it is not already well established. Courses must be

implemented, starting with grade 9, which have an IRP incorporated into them. Students in all courses need to be regularly reminded of the philosophy of the program, with its emphasis on the scientific process, and the IRP's focused on knowledge creation with a view to potentially publishing. It must be emphasized in the program that publishing work depends on the results of the research, and not on the desire of the student to publish. The level of difficulty of this step is very much dependent on the situation in the school. As noted above, schools with well-established IRP programs will need to spend little time on this step, while other schools might need to expend significant effort.

- **Publishing**
  After the research aspect of the program has been established in the science program for a year or more, it is expected that some students will begin to produce work that is worthy of consideration for publishing. Now is time to establish the capacity to publish student work. In order to do this the *Journal of Science* must be established, then the publishing process must be established and teachers trained.

  - **Establishing the *Journal of Science***
    An online Journal requires a website. Whether this is designed and managed by the lead teacher or by a member of the tech department is unimportant. It is important that the Journal be registered with the ISSN center in the country of publication. This establishes legitimacy and allows other scientists and journal indexing sites to recognize the Journal as a legitimately published academic journal.

  - **Selecting Reviewers**
    It is crucial for the integrity and validity of the published work that knowledgeable and respected Reviewers be selected and agree to participate in the program. Reviewers may be current or former teachers, or experts in the field with links to the school. Reviewers must not know the identity of the students whose work they are reviewing, in order to ensure impartiality and integrity in the selection process.

  - **Implementing the publishing process**
    The process of establishing publishing criteria and processes for an entry-level scientific journal, and then selecting, preparing, and publishing student work is probably the most unique and difficult process in this program. It is helpful if the lead teacher(s) has support from the consultant for this. Training, exemplars, and communication with the consultant during the first rounds of publishing will increase the efficiency of this process. The details of the training process for establishing publishing criteria, the selection process, and the paper writing and revision process are based on an exemplar research and publishing program. These will not be discussed here, as they are beyond the scope of this Model for Implementation.

Phase 4: Establishment and Expansion of the Research and Publishing Program

It is important that a school that is implementing the Student Research and Publishing Program understand that this program changes the culture of a science program. Rather than being only consumers of science content, students and teachers become creators of new knowledge, actively and authentically participating in the global scientific community when a paper is published. As it represents a change of culture, the full embedding of the SRPP into the science program can be expected to take years. A long-term commitment to the program is required. Ups and downs can be expected and should not be allowed to result in the abandonment of the program. Once the SRPP is well embedded within the science subject(s) of the original lead teacher(s), the school may consider expanding the SRPP to all science subjects, or even to other courses which might conduct original research, such as Psychology. The expansion of the SRPP into new subjects can be done following the same process as outlined in this Model for Implementation.

Implementation Timeline

The timeline for implementation of the Student Research and Publishing Program at a school is highly dependent on the situation at that school. However, for planning and projection purposes, estimates of the time needed for each step of the process can be made.

Steps 1 and 2 together, making the decision to adopt the SRPP and then preparing for implementation, would be expected to take approximately one to two years. One year for a school that had a science program with the IRP's already integrated into it, and two years for a school that needed to implement IRP's into their science program.

Step 3, implementation of the SRPP, would be expected to take another one to two years, again depending on the situation of the school. A school that had a strong culture of research already established could probably see its first issue of the Journal after only one year, while a school where both teachers and students had little experience with independent research could be expected to take two or more years to publish its first papers.

Step 4, embedding of the SRPP into the culture of the school, is expected to take between two and five more years, with consideration of expansion into other subjects recommended after that period.

Summary of the Model for Implementation

Implementation of the Student Research and Publishing Program in Secondary School Science can be broken into four phases:

5. **Determining the suitability of the Student Research and Publishing Program for a school**
   The characteristics and capabilities of the school must be determined to be suitable for the implementation of the SRPP.

6. **Preparation for Implementation of the Student Research and Publishing Program**
   This phase involves identifying and training the lead teachers who will implement the program, as well as ensuring that the curricular program includes an Independent Research component in courses at all levels.

7. **Implementation of the Student Research and Publishing Program**
   This involves integrating original student research into all courses, with the awareness of the possibility of having work published. Then a *Journal of Science* must be established, with its attendant selection, writing, and publishing processes defined and implemented.

8. **Establishment and Expansion of the Student Research and Publishing Program**
   Over time, a culture of scientific research and publishing will be established within the school, and the expansion of the program into other subjects can be considered. Expansion into new subjects will follow a model similar to initial implementation.

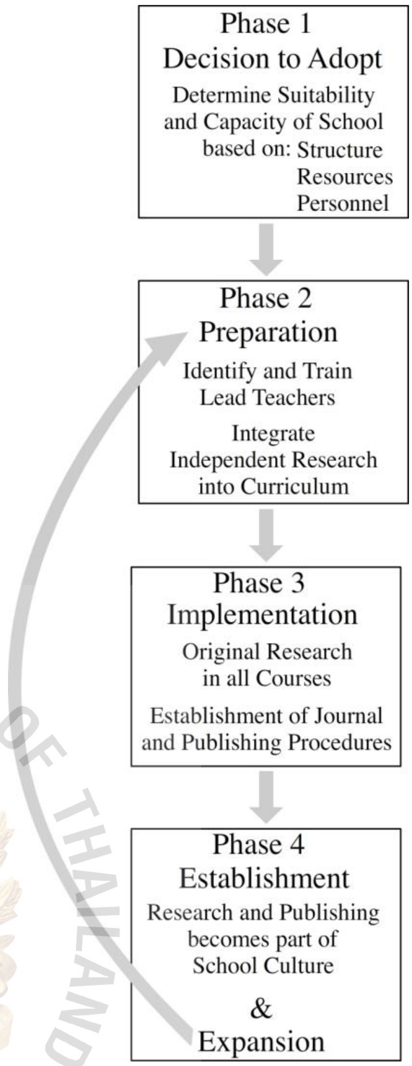


Figure 2 Model for Implementation of Student Research and Publishing Program in Secondary School Science

A visual representation of the model is shown in figure 2.

Conclusion

The Model for Implementation of a Research and Publishing Program in Secondary School Science was constructed based on data gathered from students, teachers and administrators involved in a currently successful Research and Publishing Program in Secondary School Science. Use of the Model by a secondary school is expected to lead to the establishment of a successful Student Research and Publishing Program in the Sciences.

Comments and Suggestions for Improvement of the Model for Implementation of a Research and Publishing Program in Secondary School Science.

Please rate the Model on each of the following criteria and offer comments or suggestions for improvement, if needed. Please circle or otherwise indicate your rating on the scale below each aspect.

1. **Precision**: The elements and aspects of the model are clearly described and precisely defined.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

Comments/Suggestion:……………………………………………………………

……………………………………………………………………………

……………………………………………………………………………

2. **Sufficiency**: The model as a whole is sufficient to bring about the expected result, a successful Research and Publishing Program. There are no necessary parts or steps that are missing from the Model.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

Comments/Suggestion:……………………………………………………………

……………………………………………………………………………

……………………………………………………………………………

3. **Feasibility**: All elements of the Model can be feasibly implemented by the relevant personnel in real situations.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

Comments/Suggestion:……………………………………………………………

……………………………………………………………………………

……………………………………………………………………………

4. **Effectiveness**: There is a reasonable level of confidence that correctly following the model will achieve the expected results; a successful Research and Publishing Program.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

Comments/Suggestion:……………………………………………………………

……………………………………………………………………………

……………………………………………………………………………

Assumption University

Graduate School of Education

Model Validation Approval Form

Student Name: Mr. Jonathan Eales

Contact Information: 087-518-4264, jonathae@isb.ac.th

Dissertation Title: Research and Publishing in Secondary School Science: A Study of its Effects and Development of a Model for Implementation

Model Validation Approval

Do you approve this model?

□ Yes, I, …………………………………………….have read and approve this model. I confirm that the model can be applied to successfully implement a Research and Publishing Program in Secondary School Science. My comments and suggestions are noted below.

□ No, I, ……………………………………………….have read and cannot approve this model. I confirm that the model cannot be applied to successfully implement a Research and Publishing Program in Secondary School Science. My comments, reservations, and suggestions are noted below.

Comments/Reservations/Suggestions:

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

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…………………………………………………………………………………………

Expert Signature:……………………………………….

Date: ………………………….

APPENDIX H.2

Example of returned Model Validation Form

Comments and Suggestions for Improvement of the Model for Implementation of a Research and Publishing Program in Secondary School Science.

Please rate the Model on each of the following criteria and offer comments or suggestions for improvement, if needed. Please circle or otherwise indicate your rating on the scale below each aspect.

1. **Precision**: The elements and aspects of the model are clearly described and precisely defined.

   Strongly Disagree Disagree Neutral Agree **Strongly Agree** (circled)

   Comments/Suggestion:

   you have described the model clearly and precisely, so readers unfamiliar with the program will clearly understand its aspects and scope.

2. **Sufficiency**: The model as a whole is sufficient to bring about the expected result, a successful Research and Publishing Program. There are no necessary parts or steps that are missing from the Model.

   Strongly Disagree Disagree Neutral Agree **Strongly Agree** (circled)

   Comments/Suggestion:

   you have thoroughly considered all aspects a school would need to implement, both before and during the establishment of a program.

3. **Feasibility**: All elements of the Model can be feasibly implemented by the relevant personnel in real situations.

   Strongly Disagree Disagree Neutral Agree **Strongly Agree** (circled)

   Comments/Suggestion:

   Given that external conditions are met which are outside the model itself (funding, admin support) the program is highly feasible in a different school(s).

....

....

4. **Effectiveness**: There is a reasonable level of confidence that correctly following the model will achieve the expected results; a successful Research and Publishing Program.

Strongly Disagree   Disagree   Neutral   Agree   (Strongly Agree)

Comments/Suggestion:

Your research has shown the educational benefit, both academically and in the affective domain, of an RPP. The results are very clear, and validating for teachers involved in the program at ISB.

Assumption University

Graduate School of Education

Model Validation Approval Form

Student Name: Mr. Jonathan Eales

Contact Information: 087-518-4264, jonathae@isb.ac.th

Dissertation Title: Research and Publishing in Secondary School Science: A Study of its Effects and Development of a Model for Implementation

Model Validation Approval

Do you approve this model?

☒ Yes, I, Brenda H. Perkins have read and approve this model. I confirm that the model can be applied to successfully implement a Research and Publishing Program in Secondary School Science. My comments and suggestions are noted below.

□ No, I, ... have read and cannot approve this model. I confirm that the model cannot be applied to successfully implement a Research and Publishing Program in Secondary School Science. My comments, reservations, and suggestions are noted below.

Comments/Reservations/Suggestions:

Your validation report is very clear and concise, with all aspects of the model explained and requirements for implementation in other schools carefully considered.

Expert Signature: Brenda Perkins

Date: 01 June 2014

If you want to email the forms back to me, it is okay to just type your name for your signature.

APPENDIX H.3

Collated Ratings and Comments from returned Model Validation Forms

The following is a summary of the ratings and comments of the experts who validated the Model. The four outside educational experts who responded are indicated by E1-E4. The Administrators are identified by A1-A3, the Teachers by T1-T4, and the Students by S1-S5.

Vali-dator	Model Precision	
	Rating	Comments
E1	5	The steps required are clearly detailed and set out in order. A school contemplating such an implementation should be in no doubt about the extent of the commitment and time needed to do this.
E2	5	All crucial points of the RPP model are laid out clearly in the text and carefully written in phases. Besides those crucial points in bold by the researcher, I particularly like those I highlight in blue. This is a model of high potential in nurturing young scientists since high school level through the scientific process of inquiry: from guided inquiry to open inquiry.
E3	4	Phase1: Determining the suitability of the RPP. 1. The first portion of this phase involved the topic Administrative Flexibility, Curriculum (in term of curriculum implementation) and Class size. These sound like academic arrangement rather than the structure of a school that may be interpreted in the form of organization structure. 2. Detail on the class size seems to be too rigid (25 or less are needed for) Can it be put in term of recommendation rather than requirement?
E4	4	This is well defined and presented, except for one aspect: Training of a lead teacher. Just saying that there are probably many online resources to train a teacher for such an important role is insufficient. I would like to see a more solid description of what the training would look like. I think it is important.
A1	4	Jonathan the model you describe would be expected to draw heavily on your own experience and as such I think it is described well but it is quite context specific, so as I read it I see you describing ISB which is a very well resourced school with a particular set of characteristics and culture that are not necessarily typical outside of our region.
A2	5	The model is well defined in this document and provides a good deal of precision for an unfamiliar school or institution to adopt the RPP model in a secondary school context.
A3	5	
T1	5	You have described the model clearly and precisely, so readers unfamiliar with the program will clearly understand its aspects and scope.
T2	5	Minor thing – In phase 2, final bullet, I would say "Student recognition of achievement" or something, because I think at first it could be confused with recognizing that the student has work that could be published.
T3	4	

Vali-dator	Model Precision (continued)	
	Rating	**Comments**
T4	5	The elements and aspects of the model are clearly described and precisely defined outside of minor comments on word choice included as comments in body of paper.
S1	5	Even as a student, I felt that the descriptions of the steps required for a successful implementation of RPP were very clear. I did occasionally have questions on certain areas, but they were immediately cleared up after reading a few more lines/paragraphs. If there is anything can be improved, I think it's a slight addition to the Physical and Capital Resources section. I feel that this could be modified to include the fact that elementary tools can cleverly be used together to design an effective experiment, even if a specific type of equipment cannot be accessed. From my own experience, this increased my creativity and helped me understand exactly how certain equipment worked. Thus, I progressively became better at designing scientific experiments in both Physics and Chemistry.
S2	4	
S3	5	The Model clearly explains the necessary procedures for different types of schools systems, as well as provides a strong backbone for the majority to follow. When able it also gives estimated figures for certain aspects like time.
S4	5	Everything is very clearly set into guidelines (i.e. requirements for a successful RPP, time frame to be expected). (I might be putting this into the wrong category but) There are some areas that are vague in comparison to the extremely detailed instructions. The ones that stood out to me most were the consultant: who is this person? Where does s/he come from? What kind of training do they have? How can they be guaranteed to guide the lead teacher? The reviewers: at first it was unclear what this person was reviewing altogether until the very end when you mention the anonymity of the students. If I had no experience with the process I probably wouldn't understand this part. Preparing the curricular research program: this paragraph is a little bit confusing
S5	5	
	4.6	**Average Precision Rating**

Vali-dator	Model Sufficiency	
	Rating	Comments
E1	4	… with one exception. Under the heading “Develop expertise in the skill set needed to implement and run the program, including:” I suggest including the compilation of an archive of exemplars and published work at the appropriate level and suggestions for topics to be supplied to students to assist them in making wise choices for suitable topics
E2	5	In terms of communication, some improvement of the image (the triangle on p.2) is needed to make the image corresponding with the text: (1) “scientific investigation” or “scientific inquiry”, which is integral of the whole process, is missing in the RPP process of mastering current knowledge and creating new knowledge. (2) IRP (independent research project) is also mentioned in several places in the model and thus should be added to the image (or not?) if the image is to serve as a quick conceptualization of RPP?
E3	4	No Comments
E4	3	While I expect that this program would lead to a successful RPP, I would like to see some evidence that is alluded to in the introduction but none was presented. In addition, if one uses the word “successful”, then it is necessary to explain what that means. By adding both to the model description, it would make it very compelling.
A1	4	Before I read your work I had a think about what makes our / your RPP successful and like you I would honestly say it comes down to a person with a passion. Which I have seen in several science departments in several schools your passion is channeling towards a publication in another instances it was linked to community service and cooker efficiency in Tz (developed through long term experimentation and scientific consideration). The model as a whole, yes I agree but you could probably miss several elements without any real issue – remove the one passionate driver and it will be undone. I think during my interview I described an example of teacher research being published 20 years ago in a school I worked in it was great but the project left with the driver! Not that the school’s professional community collapsed with their departure – it just changed.
A2	4	The aspiration that having a passionate and dedicated teacher is important, as is the inquiry based learning model that ensures students are prepared through the IRP procedures to take the next step toward developing an RPP. Some of the facilities and resources are not always necessary. They could well limit the scope of future RPP projects but they should not totally deny the teacher or school the opportunity to implement. The same should be said of class size. This program is will only appeal to a smallish group of students each year and therefore these other constraints are not necessarily that critical in determining success. The ability of teachers to work collaboratively to support the program is more critical.
A3	5	

Vali-dator	Model Sufficiency (Continued)	
	Rating	Comments
T1	5	You have thoroughly considered all aspects a school would need to implement, both before and during the establishment of a program.
T2	4	However, for all the emphasis on training teachers, I also think that selecting reviewers should be bolded as a potential hurdle. I think, for some schools, this might be very challenging in terms of finding someone with the time, expertise, understanding of students' abilities, etc. I would recommend training from the consultant, similar to what the teachers receive, but maybe shorter.
T3	4	I would add that getting teacher buy in important. It may not be suitable for all teachers/teaching styles. It's not possible to force teachers to do it and do it well so practically I think the model should allow for some opt out.
T4	4	I would emphasize more the importance of establishing a "Writing Guide" in Phase 2: Preparation for Implementation of the Research and Publishing Program, either as part of • Training the lead teacher(s) or • Preparing the curricular research program. The "Writing Guide" supports the skills development of all students (not just the 10-20% of students who publish a paper) for scientific research, writing and presentation skills. As well, it supports the establishment of a school culture of scientific research. I would also emphasize more that implementation of the Research and Publishing Program can start with just the science subject(s) of the original lead teacher(s) and need not involve all sciences (nor all grades) initially. I think the gradual launch of the RPP at ISB starting with physics initially and limited to certain grade-levels may be a more attractive, feasible and successful model for other schools as well.
S1	5	I have no expertise on education or implementation of educational strategies, but the steps presented in this model seem to be enough for a successful RPP. But a slight addition can be made prior to intensely implanting the model, and that is a public announcement to not only the school faculty, but also the students and parents. There will be motivated students who will be excited about the RPP and there definitely will be parents who will want to have their kids participate in the program. Parents' interests, in my opinion, play a huge role in their children's interests, especially in Asian cultures, and by publicly announcing the plan to implement this model to the entire school community, both the faculty and families will be supportive, which will give the lead teacher confidence to pursue this model and allow the implementation process to be more effective.
S2	4	
S3	4	Generally the Model sufficiently describes how to bring about a successful program, but there are other factors such as student body influencing that could be approached. Upperclassman conducting their IRPs can change the "culture" of a school by demonstrating their research to the underclassmen, thereby encouraging them to pursue publishing papers even more.
S4	4	
S5	5	
	4.2	**Average Sufficiency Rating**

Vali-dator	Model Feasibility	
	Rating	**Comments**
E1	5	The critical requirement for suitable faculty is spelt out very clearly
E2	4	The RPP model is quite demanding, yet very realistic and clear in steps. To find a passionate and dedicated, well trained teacher and passionate consultant, however, who both love to write and be patient with novice writings is not easy.
E3	3	Phase3: Implementation The implementation starting with grade 9 and come up to grade 12 totally 4 academic years whereby the school system on which most schools follow is 6-3-3 i.e. 3 years of upper level of secondary schooling. It means that the starting year is at the lower level of secondary schooling for which the science curriculum of the two levels are, to some certain extent, different from each other in the design and implementation. Perhaps this particular point deserves to be taken into account. Phase4: Establishment and Expansion Once the RPP is well embedded within a science subject, the *Journal of Science* has already been established, expending the RPP to other science subjects is thus not necessary to include this component, except the expansion is to be carried out towards subjects other than sciences
E4	4	As this model is already being used, then it is a foregone conclusion. However, for it to work in other schools, as Jonathan stated, the lead teacher must be well trained. I repeat that this aspect must be addressed in further detail.
A1	3.5	The programme implementation hinges on someone selecting the right person to implement the programme? Not sure what more you need – like to talk? (I see this as having real potential in a national system where a government or funding body were keen to raise the level of science through teacher incentives and a well funded programme i.e. using extrinsic motivators.)
A2	4	I think the model is very feasible but does rely on the right educational climate that is open to these types of initiatives, especially the administration who can clear away any road blocks. Also the other members of the Science Department should be encouraging and supportive of stretching students' academic progress in this direction. One other area that should be emphasized is the ability for students to write in a clear, logical and appropriate manner to support this type of project. This takes time to embed in a school setting that does not emphasis this type of writing.
A3	4	May be heavily dependent on specific institution but drawbacks and concerns were noted in the review.
T1	5	Give that external conditions are met which are outside the model itself (funding, admin support), the program is highly feasible in a different school(s).
T2	5	With the understanding that for a fair number of schools, they will not meet the criteria and are not in a position to implement the Model.
T3	4	Finding suitable reviewers could be a real problem. This may have to be a paid responsibility.
T4	5	

Vali-dator	Model Feasibility (Continued)	
	Rating	**Comments**
S1	4	I do agree with the above statement regarding feasibility, but I do see some major hardships of implementing such systems in the Korean (and possibly other Asian) culture that I, although never experienced, heard of a countless number of times. Korea's educational system aims to get students into good colleges, and that usually requires them to memorize, and not think creatively, like the RPP requires them to. Although the RPP would be hugely beneficial to them in terms of their ability to understand concepts better, there really is no benefit for them in terms of getting into college and finding a well-paying job. Colleges in Korea look for students with outstanding academic records, and academic records come from thousands of hours of memorizing content and problem solving, which are not compatible with the system of education the RPP requires. However, I do strongly believe that the model can be feasibly implemented in real situations, namely international schools and schools that promote well-rounded education. If the financial and physical problems can be overcome, and the educational system is compatible, I feel that this Model will be highly effective. But in cultural societies like the Korean one I described, it'll still be possibly, but just much more difficult, to implement this model in Korean (and some other Asian) public schools.
S2	4	
S3	3	*I'm not too comfortable answering this questions as I, the student, do not grasp well enough the complexity of planning, and executing such a large program. That said, the Model bluntly sections off the requirements from each member of the school community.
S4	5	Your instructions for staff and admin is pretty intense ("a teacher who is scientifically and pedagogically competent, and is passionate about, and committed to..."), but overall very clear and hopeful for a variety of schools.
S5	4	School structure/requirements described are quite demanding – especially in terms of administration support and quality of lead teacher.
	4.2	**Average Feasibility Rating**

Vali-dator	Model Effectiveness	
	Rating	**Comments**
E1	5	As with every ambitious project breaking new ground there may be unforeseen difficulties – critical faculty may suddenly leave the school and/or administrations may change or faculty may find the learning curve steeper than they had imagined. With patience and commitment I see no reason why the program cannot be established along these guidelines in suitable schools. Note: many elements of the program are very similar to that proposed by IB for 2015 onwards, the final step to publishing will in the future be not such a daunting challenge.
E2	5	There is no doubt that once implemented, the RPP will yield the expected results in highly motivated, committed students.
E3	4	For the sustainability of the effectiveness of the program, two vital factors are highly emphasized to all concerned people and agencies. They are 1. The teacher, who are passionate about, and strongly committed, to implementing the RPP. 2. The students, who are committed to excel in science.
E4	3	Again, I must stress that "successful" needs to be defined, or have a list of outcomes/criteria that would explain success of the model.
A1	4.5	Same thought – with the right person yes! And in the case of ISB we are fortunate to have your RPP and all that it brings to our kids – thanks.
A2	4	This program is effective in promoting the importance of Science as a field of discovery and therefore prompts Science and a future career option.
A3	5	
T1	5	your research has shown the educational benefit, both academically and in the affective domain, of an RPP. The results are very clear, and validating for teachers involved in the program at ISB.
T2	5	With the understanding that for a fair number of schools, they will not meet the criteria and are not in a position to implement the Model.
T3	4	Embedding into school culture would require it to spread outside the science department and serious commitment from Admin and teachers. If many external exam boards recognizing these skills (as the IB do to some extent with the extended essay and there new practical programme) this would also help it's development.
T4	5	If comments/suggestions noted in 2. **Sufficiency** above as well as from other validators are made, then I have a reasonable level of confidence that correctly following the model will achieve the expected results.

Vali-dator	Model Effectiveness (Continued)	
	Rating	**Comments**
S1	5	This model provides a very detailed, step-by-step process of achieving a successful RPP. Although it would take quite some time, I believe that the model will bring expected results, as long as the model is followed very carefully. Being a student, I cannot say much on the effectiveness of the model since there are so many aspects, other than student motivation and desire, to be considered. However, I do believe that as long as schools fit the description of a "suitable school" mentioned in this model, the RPP can be effectively implemented in time.
S2	4	
S3	4	Given that there will be exceptions, and that the Model was based on an International School, this model regardless manages to retain levels of confidence appropriate to be used/viewed by other schools.
S4	5	
S5	4	The model described seem somewhat over-specified and perhaps a bit too rigid or difficult to understand for an implementer without the appropriate contextual understanding – it is like describing something that may be more easily understood through an example. It is great that clear directions are given, but I believe it should be stressed that implementation of this model may yield successful results even without fulfilling every single component specified (correct me if I am wrong). I don't know how these models are typically structured and used, but perhaps the user/implementer of the model will benefit from a list of requirements along with its corresponding degree of importance for ease of a big picture understanding – a slightly more detailed version of figure 2 in text form.
	4.5	**Average Effectiveness Rating**

Vali-dator	Model Validation Overall	
	Rating	**General Comments**
E1	Approve	I have made one recommendation above for addition to the list of things a teacher needs to do. With that slight reservation I commend the writer for a thorough job which will be of great value to a school contemplating the program.
E2	Approve	
E3	Approve	
E4	Approve	The model is well presented and has been implemented in an international school. My approval is contingent on three things: 1. Describing in better detail how a lead teacher is trained, 2. Evidence that the ISB model improves student achievement as claimed, and 3. Presentation of criteria for what a "successful" RPP looks like
A1	Approve	My reservations have been outlined above. I have seen the model implemented very successfully in one context and have no doubt it could be replicated with the appointment of the right individual in different school settings.
A2	Approve	This is a good initiative to engage students in the scientific process and it should be stressed, to try and succeed or fail in their attempt to find original material to publish. One of the most important aspects of this type of project is to realize that not every attempt is going to be successful and this is perfectly OK because Science does not always yield perfect solutions and will regularly take many years to perfect the necessary outcome. It is exciting for those involved because it takes them to the next level and within reason allows students to develop new skills and greater appreciation of the challenges Scientists face. Discovery, inquiry and innovation are great attributes to cultivate, and the program allows students to do this as either individuals or in collaborative teams.
A3	Approve	In reading the review with a limited background or expertise in scientific theory, research, or investigation I was still able to articulate the model and fully understand and comprehend the described implementation from beginning to end. In fact I have shared key ideas and concepts with colleagues outside of ISB and strongly feel that this review can alone serve as a detailed guide from aligning curriculum all the way to the publishing process. It should not be undervalued that successful implementation will depend on school culture, lead teacher expertise and capacity and student passion, motivation, and academic ability. Fortunately all factors exist at ISB and the program has been proven to be successful and extremely valuable for students. Of course certain aspects continue to evolve including specifying concessions for the lead teacher, capturing interest and involvement from all department members, expanding beyond traditional science disciplines, and student capacity – students at ISB work extremely hard as is in all disciplines and are often stressed and over committed.

Vali-dator	Model Validation Overall (Continued)	
	Rating	**General Comments**
T1	Approve	Your validation report is very clear and concise, with all aspects of the model explained and requirements for implementation in other schools carefully considered.
T2	Approve	
T3	Approve	
T4	Approve	See previous comments.
S1	Approve	I am very confident that schools that want to establish the RPP can successfully implement this model. This model is very detailed and takes the reader through a step-by-step process by which schools can achieve success and start their own RPP. I have had a great privilege of being a part of such a well-developed RPP and I have been able to see how beneficial and effective it is at ISB. Thus, I am almost certain that if the guidelines in this model are followed carefully with patience and a motivation to truly implement the program, schools will achieve success.
S2	Approve	
S3	Approve	The concept of school culture is a difficult one to approach, as possible variations may occur for time of completion.
S4	Approve	Sometimes you switch from really formal and fancy language to much more colloquial stuff ("ups and downs" etc.) but if you don't mind then I'm sure it won't make much of a difference. Other than that everything looks really good.
S5	Approve	For evaluative and practical implementation purposes, a table-type graphic that maps the number of requirements achieved to expected results may also be useful in the model specification. This mapping does not need to cover the complete permutation of requirement fulfilled, but may want to cover the typical cases and shortfalls . See example table below.

BIOGRAPHY

Jonathan Lee Eales

Education

1987 Bachelor of Science in Physics and Secondary Education
Wheaton College, IL, USA

1995 Master of Science in Physics Teaching
Delaware State University, DE, USA

Experience

2001-Present Science Teacher at International School Bangkok, Thailand
- Founder and Editor of *ISB Journal of Science*

1995-2001 Science Teacher at Ruamrudee International School, Thailand
1991-1994
- Developed and Implemented AP & IB Physics Programs