Inquiry: The Key to Exemplary Science

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Edited by Robert E. Yager

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The Centrality of Inquiry for Teaching and Learning Science

Robert E. Yager
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Inquiry has become a revered term in science education. It is central to the National Science Education Standards (NSES) as a form of content as well as a way to teach (i.e., having a curriculum component as well as describing more desirable teaching strategies). Further, the term *inquiry* is something nearly all persons accept—perhaps blindly or without careful thought. Desirability and lack of fault may make it important and attainable; unfortunately though, it is often accomplished by mere proclamation. Most textbooks, curriculum frameworks, teaching activities, and government agencies (local, state, and national) claim to provide avenues for achieving and experiencing inquiry. Perhaps clarification of the term is needed; perhaps the term has too many forms, too many levels, too many uses, and too many different functions to be meaningful as reforms are sought in science education.

The NSES refer to inquiry throughout the 262-page document (NRC 1996). In addition, a supplementary monograph was published four years after the release of the Standards (NRC 2000). The 202-page companion to the NSES illustrates the deemed importance assigned to the term. Bruce Alberts, President of the National Academy of Science, offered analyses that indicated a needed elaboration of inquiry; in the foreword of the new inquiry monograph he says:

> *Inquiry is in part a state of mind—that of inquisitiveness. Most young children are naturally curious. They care enough to ask "why" and "how" questions. But if adults dismiss their incessant questions as silly and uninteresting, students can lose this gift of curiosity. Visit any second-grade classroom and you will generally find a class bursting with energy and excitement, where children are eager to make new observations and try to figure things out. What a contrast with many eighth-grade classes, where the students so often seem bored and disengaged from learning and from school! (NRC 2000, p. xii)*

The challenge for all who want to improve education is to create an educational system that exploits the natural curiosity of children so that they maintain their motivation for learning not only during their school years but throughout life. Alberts asserted further that we need to convince teachers and parents of the importance of children's "why" questions. He was reminded of the profound effect that Richard Feynman's father had on his development as a scientist. One summer, in the Catskill Mountains of New York when Feynman was a boy, another boy asked him, "See that bird. What kind of bird is that?" Feynman, answered "I haven't the slightest idea." The other boy replied, "Your father doesn't teach you anything!" But his father had taught Feynman about the bird—though in his own way. As Feynman recalls his father's words:

> *"See that bird? It's a Spencer's warbler." (I knew he didn't know the real name.)*
>
> *"You can know the name of that bird in all the languages of the world, but when you're finished, you'll know absolutely nothing whatever about the bird. You'll only know about humans in different places and what they call the bird. So let's look at the bird and see what it's doing—that's what counts." (NRC 2000, p. xiv)*
>
> *Alberts argues that the inquiry process must begin in kindergarten and continue, with age-appropriate challenges, at each grade level. He writes, "Students must be challenged but also rewarded with the joy of solving a problem with which they have struggled. In this way, students recognize that they are capable of tackling harder and harder problems. As they acquire the tools and habits of inquiry, they see themselves learn. There can be nothing more gratifying, or more important, in science education." (NRC 2000, p. xiv)*

Inquiry was chosen as the theme for the sixth Exemplary Science Program (ESP) monograph because of its centrality to how science is defined and to illustrate various ways inquiry can be approached. It is not another textbook, a platform for teaching at all K–12 levels, a set of clever activities, or a new kit full of explicit and precise directions for teachers who may be willing to try them. Many nominations for inclusion in this monograph centered on materials and use of prepared lessons. Many provided no evidence of program impacts and successes. The various chapters *do* include ideas, show relationships to the NSES goals, and illustrate the *More Emphasis* situations that summarize each chapter concerning the acts of teaching, the nature of needed professional development of teachers, the elaboration of the essential features of inquiry, the nature of the total curriculum framework, and the systems of needed support and structure. All of these can be used to illustrate the centrality of the learner for understanding and using inquiry.

The table "Essential Features of Classroom Inquiry" (NRC 2000, p. 29) was shared with all persons and programs nominated for inclusion in this monograph. This table indicates levels of variations of use of inquiry in indicating degree of self-direction for students and the quantity of directions from teachers and/or provided by the instructional materials used. Although these five "essential features" are included in several chapters, they appear below to illustrate the framework we used in our search for exemplary programs that illustrate these features, and the degree in which each is teacher- or student-centered:

- Learner engages in scientifically oriented questions.
- Learner gives priority to evidence in responding to questions.
- Learner formulates explanations from evidence.

- Learner connects explanations to scientific knowledge.
- Learner communicates and justifies explanations.

The National Advisory Board for the Exemplary Science series pushed for as much student-centeredness and use of inquiry in every aspect of the program outlines as possible. This included all the organizational frameworks for the NSES, focus on the four goals for teaching science, the nine ways science teaching should be defined, the need for continuing teacher education, the nature of appropriate assessments, and the specific content exemplifying inquiry. Many nominations and initial outlines were rejected and others withdrawn when authors reflected on the features indicated as essential.

Each facet of the NSES begins with an elaboration of the eight features of science content that are recognized and advocated. The first of these eight was discussed as a general preamble to each facet—but there was fear that too many would merely look at the listed features and not even consider the one that was offered as most important. It remains the one left out of most attempts or Pathways to NSES, to current lives, to activities, to assessments. In another sense this first one is designed to illustrate all features of inquiry. This first form of content is the "unification of science concepts and processes." It is recommended that this must be done in context—not allowing individual content to deal exclusively with important concepts of science or a focus on process skills. Such a program was first developed as *Science: A Process Approach* (SAPA) (American Association for the Advancement of Science [AAAS] 1968) and recommended for K–8 schools in the late 1960s. Traditionally such a two-pronged view of science consisting of concepts and processes does not help with science learning or the meeting of any of the student goals. Concepts taught merely as definitions and processes taught as isolated skills are rarely successful for anything other than for students to remember as prescribed and used as assessments of their "learning." But, such tests rarely are accurate measures of real learning.

The first of the four goals also is another way of looking at an inquiry focus. For some this first goal is the one that should be given the most effort and attention; it is argued by some that it should represent 50% of the focus for a given K–12 science course. This goal calls for every student (every year) to experience the richness and excitement of knowing about and understanding the natural world. This experience and excitement comes from students who are involved with the five essential features of inquiry. The first and most important of these is starting with student questions, which serve to indicate their curiosities. Curiosity is something all humans have. Unfortunately it tends to disappear the longer students study science in school. Albert's opening statement that "Inquiry is in part a state of mind" illustrates well this first aspect of experiencing inquiry phenomena.

The NSES goals also call for science for meeting daily and personal challenges—again focusing on student-centered instruction that can be used in and outside of school. A third goal calls for students working on school, community, state, national, and/or world problems (e.g., environment, energy, weather, or health hazards). The fourth and last goal focuses on awareness and understanding of possible careers in science and/or technology. Inquiry can be a focus for meeting all four goals.

This look at inquiry also assumes a common view of both science and technology, in terms of the exemplars and those who will learn from them. Several exciting new programs, as well as several reform efforts undertaken over the past half century, have considered the history and philosophy of science. These considerations are again included as one of the eight facets of science content included in the NSES. None of the best efforts at meeting this goal have resulted in many changes, other than defining a desired curriculum and then expecting teachers to use it. Such efforts to deal with the meaning and history of science are often portrayed as exhibiting inquiry.

At times, scientists and science educators have tried to standardize and outline in general terms a definition for the human activity called science. One of the most influential scientists in the United States was G. G. Simpson, who proclaimed science to be "the exploration of the material universe with attempts to explain the objects and events encountered—keeping in mind that the explanations offered must be testable" (1963, p. 81). Many use these attributes to identify the precise aspects of the activities characterizing the explanations proposed and the evidence produced and/or available to support the possible explanations offered. This sequence is sometimes characterized with the following five steps:

- formulating questions about the objects and events found/observed in the natural world;
- offering explanations for the objects and events encountered (hypotheses formation);
- testing for the validity of explanations offered;
- communicating the results to others; and
- confirming that the results are compatible with "established" views or that they represent new understandings and theories not previously known, proposed, nor accepted.

These features of science also define the major aspects of inquiry. Some argue that the results are more important and better indicators of learning if the results can be used in new contexts and by other people. But, too often students are never expected to propose such uses; some teachers spend much time suggesting other contexts in test items, which represent possible contexts the teachers identify, not something students are expected to do.

There have been attempts to move school science beyond science known and practiced by scientists. There have been attempts to unite science with the field of technology—unlike the efforts in the late 1950s and early 1960s, which sought to remove technology from science and relegate it to "the shop" and designate it as appropriate for non–college bound students. But newer programs have tried to reverse this and recognize that technology—that is, focus on the design world—is seen by most people as more interesting, useful, and product-oriented than pure science. The major difference between science and technology is that one has to accept the natural world as it is found in science endeavors. When it comes to technology, though, the answer is always known, as we use phenomena and explanations from the natural world (science) to develop devices seen as useful to human existence. The differences remain, but the domains and activities characterizing both are intertwined. In some ways schools do a disservice to treat them as separate.

Many attempt to explain inquiry, often varying views of it, to develop inquiry activities, and/or to specify Scientific inquiry (always with a capitol "S") all for intended use in casting science as inquiry—but accomplished and directed by teachers. These are teacher-driven efforts to encourage greater learning for understanding especially for the most "gifted." Others (e.g., Eastwell 2007) try to define types of inquiry as confirmational, structured, guided, and/or open.

Others have proposed adjectives like "coupled" or "full." All of these raise questions about the real need for modifiers before using the term *inquiry*. Such attempts to specify differences raise issues about grade levels, past experiences, interests, choices for use, relative importance, and specific procedures for meeting any of the four NSES goals offered for teaching science.

Paul Hurd (1978), one of the most prolific and informed science educators in the United States, caused quite a stir when he offered the following statement about inquiry:

> *The development of inquiry skills as a major goal of instruction in science appears to have had only a minimal effect on secondary school teaching. The rhetoric about inquiry and process teaching greatly exceeds both the research on the subject and the classroom practice. The validity of the inquiry goal itself could profit from more scholarly interchange and confrontation even if it is simply to recognize that science is not totally confined to logical processes and data-gathering. (p. 62)*

Perhaps this monograph will serve to illustrate various forms of inquiry while also beginning the effort to back up such impressive examples in terms of planning and execution—with actual assessment of the effectiveness of the programs in terms of student learning, development of more positive attitudes, and actual abilities of students to use concepts and skills in completely new situations.

Carl Sagan (1998) has written that everyone starts out as scientists; i.e., full of questions about the objects and events around them. A uniqueness of humans is not only curiosity, but the desire to satisfy it. All humans do it; e.g., poets, musicians, artists, and religious leaders. And, of course, scientists do it too! But the uniqueness is that in science the proposed answers/explanations must be accompanied by evidence concerning their validity. The evidence must be used to convince others (the science establishment) that the explanations are accurate ones. When this is accomplished, the information can be used and becomes a part of the framework for the inquirer. It is interesting to note the changes in perceptions and understandings over time. Studying the history of science can be a fine way to understand science as well as inquiry.

All students come to places called schools with many experiences. Perhaps too many are willing to believe teachers, parents, grandparents, or friends for satisfying their curiosities too quickly, or without questioning and the actual gathering of evidence for the answers they offer. In schools, teachers are always right! But, why do schools not take advantage of curiosities, personal explanations, and use them to illustrate science itself? Instead, we tend to give our students the explanations and language used by professionals. If they know terms, do they know science? Many students only know definitions with no real context or meaning or potential use. This is related to the Feynman point about naming birds, included earlier in this introduction. We are trapped into being transmitters of the known and fail to approach dealing with the unknown. We tend to short-cut the process of science itself. We are poor at collecting our own evidences for the validity of personally offered ideas.

Do we really need to expand on the simple definition for inquiry? Do we need to do more than to encourage our students to question, to explore, and to provide evidence for the validity of the explanations offered, and to share the evidence and thinking with others? Do we all understand science as a form of personal inquiry? Do the Exemplars described in the following chapters provide platforms for raising more questions? I hope so!

Feynman (1985) has written that science consists of persons called scientists who deal with three foci that define science in other ways. These include persons who (1) deal with the things that they know they don't know (this is where most practicing scientists work), (2) deal with the things they "know" that are not so (often very difficult to identify), and (3) deal with the things that they do not even know that they don't know (an impossibility). Perhaps this is a view of science that science educators should consider more. Instead, we want to teach students to follow directions (directly or guided) or to "confirm" what they are told or read about to be true. We do not question textbooks, kits, labs, or curricula that are labeled as "inquiries." Are we good models of inquiry in our own views of teaching? Should we profess less and participate more in questioning, explaining, and testing explanations for validity? Why do we leave our students with fewer questions after our instruction than before real science experiences begin? Why do we not care more about the fact that students are less curious after instruction than before and have more negative views of science, science careers, and science teachers? Let's continue to listen, to encourage, and to support thinking and curiosity that characterize inquiry and science itself. Perhaps one of the problems is that too few science teachers have even had a full experience with science themselves! How many view science teaching as a form of science?

In one sense, inquiry can be used as a synonym for science. Both include starting with questions, collecting evidence concerning the explanations offered, and arguing with others about the validity of the explanations. Science is a continuing quest for better understanding of the natural universe. This quest is inquiry! This quest for exemplars has led to this sixth Exemplary Science Program Monograph in the NSTA series. Those of us involved with reviewing submissions have been impressed—but still full of questions and anxious to learn of the next iterations. We will also be interested in the reactions of the authors as they continue to share their experiences at NSTA conferences. We expect all to continue to grow, to change, and to enjoy inquiry teaching more each year. We encourage teachers of every school grade level as well as those at colleges to continue to improve and make the process a basic ingredient of teaching and to recognize teaching a part of what defines science itself.

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Robert E. Yager—an active contributor to the development of the National Science Education Standards—has devoted his life to teaching, writing, and advocating on behalf of science education worldwide. Having started his career as a high school science teacher, he has been a professor of science education at the University of Iowa since 1956. He has also served as president of seven national organizations, including NSTA, and has been involved in teacher education in Japan, Korea, Taiwan, and Europe. Among his many publications are several NSTA books, including *Focus on Excellence* and *What Research Says to the Science Teacher.* Yager earned a bachelor's degree in biology from the University of Northern Iowa and master's and doctoral degrees in plant physiology from the University of Iowa.

Student Inquiry and Research: Developing Students' Authentic Inquiry Skills

Judith A. Scheppler, Susan Styer, Donald Dosch, Joseph Traina, and Christopher Kolar
Illinois Mathematics and Science Academy

Research is formalized curiosity. It is poking and prying with a purpose.
—Zora Neale Hurston, in Dust Tracks on a Road, 1942

Established by the state of Illinois in 1985 to develop talent and leadership in science, technology, engineering, and mathematics (STEM), the Illinois Mathematics and Science Academy (IMSA) has become an internationally recognized educational learning laboratory that inspires, challenges, and nurtures talented students. Our advanced, residential, college preparatory program prepares 650 talented Illinois students in grades 10, 11, and 12 to become scholars, researchers, and entrepreneurs. Toward this end, we find that about 80% of our graduates obtain STEM bachelor's degrees.

IMSA has a long history of supporting, nurturing, and promoting high school student participation in research through our academic curriculum and the Student Inquiry and Research (SIR) program. In 2008, we completed our 22nd year as a math and science academy; for 20 of these years we have had a student research program that now numbers approximately 3,300 cumulative student participants. The SIR program supports student research not only in science, technology, engineering, and mathematics (STEM) fields (about 75% of participants), but also in the fine arts fields (<5%) and the social, behavioral, and economic science (SBES) fields (~20%). Participation in SIR for IMSA juniors and seniors is on a voluntary basis, but in recent years, as institutional support for SIR has grown, the student participation rate has reached 67–75%.

In the 2005 NSTA monograph *Exemplary Science in Grades 9–12: Standards-Based Success Stories*, we presented and discussed student inquiry at IMSA (Scheppler et al. 2005). This monograph focused on the on-campus portion of the SIR program for STEM investigations. Evaluation and evolution of the SIR program has led us to consolidate and standardize the experiences for students pursuing work both on campus and off campus. What we have learned from having students conduct inquiry investigations and the rethinking of our science program led us to design, develop, and implement a required core science course for all of our incoming sophomore students. This course helps prepare students for their own independent investigations and supports their development with respect to various habits of mind important to science. This chapter discusses the course, Methods in Scientific Inquiry (MSI), how knowledge from this course has transferred into our science elective program, and how it has improved the quality of SIR investigations that our students conduct. Also included is a discussion of our long-term successes with IMSA graduates.

Student Inquiry and Research

The SIR program is an interactive partnership that pairs students with professionals so that they can actively pursue in-depth investigations. SIR provides a framework for students to explore compelling questions of interest; conduct original research; create and invent products and services; develop businesses; share their work through presentations and publications; and collaborate with other students, advisors, inventors, researchers, and scholars throughout the world. As their skills and understanding grow, students gain increased independence in pursuing the meticulous work of real-world research projects.

Our students follow the SIR program standards, which center on planning, investigating, analyzing, and communicating; we want students to plan experiments, make observations, use multiple data sources, and come to their own defensible research conclusions. These standards have been published (Scheppler et al. 2005) and have been used at IMSA since 2004 to guide student inquiry activity and to assess student progress. On-campus and off-campus advisors guide students in this process in a variety of ways. The students who work on-campus generate their own investigation questions, use IMSA equipment and materials, and receive feedback from IMSA staff advisors. Likewise, off-campus investigations may revolve around students' questions or students may assist an advisor on that person's research. Off-campus advisors are encouraged to provide opportunities for the student in pursuit of a question totally of the student's own interest, and many are willing to guide students in this way. Some students are able to bring work from off-site institutions back to IMSA to work on, on days other than designated Inquiry days. Each student, regardless of the origin of the investigation, must articulate a well-focused question (Marbach-Ad and Sokolove 2000).

To meet the program standards, all students must articulate their question; write an investigation proposal; demonstrate engagement, learning, and accomplishment by keeping a journal; present and defend their work through both oral and poster presentations at IMSAloquium, held each spring; and write a research paper. These requirements are available on the SIR website (*www2.imsa.edu/learning/inquiry*). We continually refine these requirements and our supporting materials, but the basic content has served us well. Each requirement is assessed, frequently in both a formative and summative way. This opportunity enables some students to present their research at local, national, and international conferences and to publish their work in professional journals.

Because students determine the topic of their inquiry and with whom they will work, the learning that occurs is very personalized. They are able to explore a specific area in depth, as well as learn skills and habits of the discipline. Occasionally, this means that the student finds that he or she really is not interested in pursuing further study in the area. Other times, and for many, these experiences solidify an interest and provide a boost to future career plans.

SIR Evolution and Demographics

Beginning in 2006, the off-campus and on-campus programs making up SIR were merged into one program, with the same standards, requirements, and assessments as described for the Student Inquiry program (Scheppler 2005). While participation for juniors and seniors is still voluntary, in 2007 SIR became a nongraduation credit-bearing course at IMSA. The participation rate for the class of 2008 was 67% (140 out of 210); participation over the past eight years has remained steady. Half the class of 2008 participants (70) participated for a second year, though not necessarily pursuing the same investigation. Of the remaining, 20 students participated during their senior year only and 50 participated only during their junior year. IMSA accepts equal numbers of females and males in each entering class.

Ethnicity data show that the SIR participation does not reflect the demographics of our student body; ethnicity of the entire class of 2008 is shown in parentheses. Class of 2008 demographics for participants in SIR: 4% African American (8%), 46% Asian/Pacific Islander (35%), 1% Latino (4%), 41% Caucasian (45%), 5% multiethnic (5%), 3% not reported (2%). These results are fairly typical of any given graduating class; we are underrepresented in African American and Latino students and overrepresented in Asian/Pacific Islander students compared to the overall demographics of the class. We are currently trying to ascertain reasons this may occur and to develop ways of encouraging more and equivalent participation from all student groups.

IMSA Science Program

In 2005 the IMSA science team redesigned its core science program for sophomores. Prior to 2005, each student took a yearlong, two-credit, core course taught by one science teacher. The course was designed to encompass the content of biology, chemistry, physics, and Earth/space science, and be taught in an integrative and inquiry-based fashion. A review of the sophomore program conducted by external experts in science education indicated that inquiry teaching in this course was deficient. Also, teachers were not necessarily comfortable enough with some content to teach in an inquiry-based way when teaching outside their discipline. Teaching inquiry skills often became a pedagogical choice, not the program initiative that it was intended to be. Additionally, given that we are a school for students interested, talented, and gifted in math and science, and that those students come from all over Illinois, these students have enormously varying backgrounds in science. With an integrative common course, we did not have a mechanism for honoring student proficiency in a specific area. More specifically, we could not exempt them from a portion of a yearlong course. While integration and inquiry were occurring, we were not satisfied with the depth and extent to which they occurred. These were significant issues that led us to conclude that we were not providing our students with the best science experiences that we could offer.

After a year of conversation and redesign, the current core sophomore program was implemented. It has four one-semester courses, each worth a half credit. Three of the four courses are discipline-specific, and are taught by an instructor with an advanced degree in that field: Scientific Inquiries—Chemistry (SIC), Scientific Inquiries—Physics (SIP), and Scientific Inquiries—Biology (SIB). The fourth course is Methods in Scientific Inquiry (MSI), described in the following section, which can be taught by anyone on the science team. Our goal is still to teach all of these core courses in an inquiry-based fashion.

Our science elective program can be likened to a small college. Juniors and seniors take electives together, with no specific sequencing. There are five biology electives five chemistry electives and seven physics electives. Students at IMSA are required to take a total of four science credits, three math credits, one additional math or science credit, three English credits, two-and-a-half history/social science credits, one wellness credit, one-half fine arts credit, and two world language credits. Most students take more credits than they need in the various areas.

Methods in Scientific Inquiry

Methods in Scientific Inquiry is a one-semester, one-half credit course that is required of all IMSA sophomores. It meets twice a week for 95 minutes each. The course explicitly addresses three broad areas encompassed by the nature of science: data acquisition and analysis, experimental design, and written and oral communication. Activities support the development of basic skills across the science disciplines and promote an understanding of scientific inquiry and the nature of research.

It is our goal that students begin to develop the skills necessary to conduct a science inquiry investigation through a variety of activities that deepen with time (Table 1). The activities support the development of skills in science, as well as demonstrate discipline-appropriate thinking. Student assignments are completed individually and in small groups. After building appropriate inquiry and research skills, students have some latitude in defining a final research investigation and report their results of that investigation in the form of a paper in scientific format and an oral presentation.

The students enrolled in MSI acquire an understanding of the generative nature of scientific practice. They gain practice in designing, conducting, and communicating the results of science inquiry projects. By doing so, students gain a better understanding of the process and nature of science, the tentative nature of science knowledge, and the falsification of hypotheses. They gain practice in written and oral communication, using the format and assessments of the SIR program. Although students encounter various concepts listed in the IMSA and National Science Education Standards, it is expected that students will leave the course with a better understanding of those concepts related to engagement in the process of science and employment of historical, personal, and social perspectives with respect to the nature of science and technology (NRC 1996; IMSA 1999; NRC 2000).

Scientific research starts with a question. During the first quarter of MSI, much of class time is spent asking and answering the types of questions listed in Table 1. The purpose of MSI is to expose students to these basic types of scientific questions, collect and analyze data, and draw conclusions from evidence. The students have much freedom in the specific questions they ask. For example, information or an assertion may be presented to them and they are then asked to investigate an aspect of that claim. The course is inquiry-based, with prompts to assist students in thinking about controls, variables, replicates, and appropriate statistical analyses. A course manual containing and describing a few basic statistical tests has been prepared and is provided to the students at the beginning of the course. They are expected to choose the appropriate statistical test, based on the type of question being asked and data being collected. While we know that we will be guiding them, they are not told any specifics at the beginning of an activity. The results obtained from these activities are communicated in writing in the form of a scientific paper or orally as a presentation. We do not begin by having them write a complete

Table 1. Methods in Scientific Inquiry

Question	Class Activity	Statistics
How can I quantitatively describe the population that I have sampled?	Student choice (for example, hair thickness, heart rate, or scores on some test)	Descriptive statistics
How does one compare the means (i.e., averages) from two populations for some variable?	Student choice (for example, temperature or rainfall in different cities, or heart rates of males and females)	t-test
How does one determine if an observed set of frequencies differs from an expected set of frequencies?	Phenotypic ratio of corn plants (for example, compare an observed phenotypic ratio to some expected Mendelian ratio).	Chi-square goodness-of-fit test
What does it mean for two variables to be dependent, and how does someone determine if one variable is dependent on another?	Student choice (for example, Is the ability to taste PTC dependent on whether someone likes a specific type of food?)	Chi square test of independence
What does it mean to be correlated and how does one determine if two variables are correlated?	Student choice (for example, Is there a correlation between population size and GDP for countries in Europe, or between the free throw and field goal percentages of basketball players?)	Correlation analysis
How does one describe the mathematical relationship between X and Y variables? Also, can one variable be used to predict or estimate the other?	Buoyancy Lab (for example, What is the relationship between the density of a canister and the percent of that canister submersed in some liquid?)	Linear regression analysis
How does one compare means (i.e., averages) from multiple populations when one or more variables are involved?	Bacteria growth (for example, students alter the conditions under which bacteria are grown and compare the growth rates under three or more different treatments)	ANOVA

Part of the curriculum of MSI incorporates statistical analyses, taught in an inquiry-based fashion. Students work through various activities while experiencing and developing inquiry skills. The activities change from year-to-year as the course is refined and modified.

paper for an activity, but focus at different times on specific sections, developing their skills and understanding of the communication style in science. Discussions of the nature of science and scientific inquiry and other topics such as content of the activity or research with human subjects are embedded throughout the course at natural times.

Student performance and learning in MSI is assessed using a variety of methods, including in-class quizzes, formative and summative written assessments, homework assignments, multimedia presentations, oral reports, and written papers.

MSI culminates with students doing their own independent research investigations that they have chosen with the help of the instructor. While students are completing the beginning activities and building basic skills and abilities, they work in parallel to choose and develop a rationale and plan for an independent research investigation that they will complete during the second quarter of the course. This includes going to the library and learning about peer-reviewed scientific literature. The students are expected to have primary science sources in their final research paper. Discussions and learning at this time also include scientific literacy, credibility of sources, and appropriate use of the Internet and web resources. As the semester progresses, the independent investigation becomes the larger course focus. Students have as much freedom to choose their independent investigation as we can offer, given that we do not have unlimited resources and time. The culmination of this final project will be a written research paper and an oral presentation. Students can work in pairs to complete data collection and analysis and the oral presentation; the research paper is written separately and independently.

Student Experiences in Science Prior to IMSA

Our teaching experiences while working with students both in the science classes and in the SIR program led us to realize that students needed specific experiences in scientific inquiry. We created MSI to give our students experience in the nature of scientific inquiry and the processes of science. A survey with questions modified from the High School Survey of Student Engagement was administered to 107 IMSA sophomores, about two weeks before the end of MSI, the first semester that it was taught. These questions and a summary of the student responses are shown in Tables 2 and 3.

Table 2 shows the data obtained when students were asked about their science class experiences prior to attending IMSA. While nearly two-thirds of them reported that they engaged in hands-on science at their home schools “often” or “very often,” large percentages reported spending lots of time in science listening to the teacher and completing worksheets. Only about one-third of the students reported that they were the ones presenting and discussing the information “often” or “very often.”

We probed what they experienced, prior to coming to IMSA, when they did engage in hands-on science activities (Table 3). We found that the students had little opportunity to design their own experiments, although slightly more than half reported determining experimental controls “often” or “very often.” They had little instruction in and opportunity for using and performing statistical analyses. They were provided with few opportunities to communicate in a scientific fashion. Students also reported that they were not very engaged in science outside of school. The following percentages are totals of students who reported participating often or very often: Science Olympiad, 6.5%; science club, 8.4%; science fair, 22.4%; other activities, 16.8%. It is interesting that our IMSA students, who are coming to a math and science academy with a strong interest in STEM fields, report engagement in few science activities outside the classroom.

Student Perceptions of MSI

At the end of the first semester that MSI was offered, students were surveyed about their perceptions of the course (Tables 4, 5, 6, and 7, pp. 48–49). We were a bit surprised by the lower-than-expected percentages of students who answered “very often” or “often” to some of these questions. For example, students were using multiple sources of information—class discussions,

Table 2. Student Science Experiences Before Coming to IMSA

How much time in your home school science class did you spend…	Very often	Often	Sometimes	Never
… listening to a teacher lecturing/talking?	42.1%	40.2%	15.9%	1.9%
… completing worksheets concerning science?	36.4%	30.8%	29.0%	3.7%
… watching a teacher demonstration?	12.1%	31.8%	46.7%	9.3%
… presenting/reporting on science?	12.1%	19.6%	52.3%	15.9%
… conducting hands-on activities/labs?	34.6%	28.0%	35.5%	1.9%
… engaged in student discussion of science?	15.0%	24.3%	41.1%	19.6%

Sophomore students enrolled in MSI (n = 107) were surveyed with questions modified from the HSSSE.

Table 3. Student "Hands-On" Science Activities

If you engaged in hands-on activities how much time did you…	Very often	Often	Sometimes	Never
… follow a given protocol?	47.7%	31.8%	17.8%	2.8%
… determine experimental controls?	19.6%	32.7%	29.9%	17.8%
… choose the experiment?	4.7%	8.4%	27.1%	58.9%
… design the experiment?	7.5%	8.4%	29.0%	55.1%
… design an experiment you wanted to perform?	3.7%	2.8%	23.4%	70.1%
… perform statistical analysis?	7.5%	3.7%	9.3%	79.4%
… make graphs, tables, charts?	27.1%	23.4%	29.0%	20.6%
… write a lab report?	31.8%	20.6%	24.3%	23.4%
… write in the form of a scientific paper?	9.3%	15.0%	20.6%	55.1%
... give an oral presentation?	6.5%	15.0%	54.2%	24.3%
… make a poster presentation?	11.2%	12.1%	44.9%	30.8%

Sophomore students enrolled in MSI (n = 107) were surveyed with questions modified from the HSSSE.

the internet, books and published articles, and course handouts (Table 4, p. 48). When students were conducting each activity, they were required to use statistics, write about the investigation, and incorporate science content, so they were using concepts from different subject areas (Table 4). About two-thirds of the students selected the responses "very much" or "quite a bit" when asked if MSI emphasized understanding information, explaining meaning, and making judgments, as opposed to emphasizing memorization. Only about 50% of students selected the responses "very much" or "quite a bit" when asked if MSI contributed to their growth in writing, speaking, thinking critically, and learning on their own (Table 6). A slightly higher percentage (57.0%) reported that MSI contributed to their growth in using information technologies. When asked about their skills and some specific questions about what they actually got to do in MSI, responses were generally more positive; about two-thirds of the students, or more, felt that they could do what was asked of them in the MSI course, that they got to make choices, and that they could be creative. However, only about 50% "strongly agreed" or "agreed" that MSI was useful to them (Table 7). We attribute this lower-than-expected percentage to the fact that our talented sophomores are well schooled in a system that tends to value science as a collection of facts and less about generating those facts. Further, by administering the survey before the students have had other course work at IMSA, the results reflect an expectation on the part of students.

The students were not as positive about MSI as we were, but our perceptions were that MSI was making them think, it was improving their writing abilities, they were growing in information fluency and the use of technology, and they were becoming independent learners. We felt that some of these results were caused by the fact that the data were collected after the first year that MSI was taught. A new core science program had been put into place with MSI as one of the new courses. But MSI is not a typical content course, so students did not know what to expect. Also, being taught for the first time, there was no IMSA culture about MSI; no previous students could discuss what it was like, providing hints and tips, and letting the new sophomores know where they might apply the concepts elsewhere. These students were also new to IMSA,

Table 4. Student Perceptions of MSI

Thinking about MSI this year, how often have you …	Very often	Often	Sometimes	Never
… used information from several different sources (books, interviews, internet)?	21.5%	27.1%	40.2%	10.3%
… worked with other students during class?	62.6%	22.4%	11.2%	2.8%
… worked with other students outside of class?	33.6%	30.8%	29.0%	5.6%
… put together concepts/ideas from different subjects when completing assignments?	17.8%	29.0%	32.7%	19.6%
… participated in class discussions?	25.2%	30.8%	33.6%	9.3%

Sophomore students enrolled in MSI (n = 107) were surveyed with questions modified from the HSSSE.

Table 5. Student Perceptions of Mental Activities in MSI

How much has MSI emphasized the following mental activities:	Very much	Quite a bit	Some	Very little
Memorizing facts/ideas so that you can repeat them in similar form?	13.1%	16.8%	26.2%	43.9%
Understanding information and its meaning?	30.8%	31.8%	27.1%	10.3%
Being able to explain ideas in pretty much your own words?	36.4%	30.8%	20.6%	11.2%
Make judgments about value of information/evaluate whether conclusions are sound?	30.8%	37.4%	21.5%	10.3%

Sophomore students enrolled in MSI (n = 107) were surveyed with questions modified from the HSSSE.

Table 6. Student Perceptions of MSI's Contribution to Their Growth

How much has MSI contributed to your growth in the following areas:	Very much	Quite a bit	Some	Very little
Writing effectively?	22.4%	24.3%	36.4%	16.8%
Speaking effectively?	5.6%	12.1%	43.9%	38.3%
Thinking deeply and critically?	14.0%	31.8%	32.7%	21.5%
Using computers, information, and technology?	29.9%	27.1%	22.4%	20.6%
Learning on your own?	23.4%	27.1%	34.6%	15.0%

Sophomore students enrolled in MSI (n = 107) were surveyed with questions modified from the HSSSE.

Table 7. Student Views of Themselves in MSI

How do you feel about each of the following statements?	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
I have the skills and abilities to complete my work in MSI.	45.8%	34.6%	11.2%	5.6%	1.9%
I get to make choices about my experiments.	30.8%	45.8%	12.1%	7.5%	2.8%
I have opportunities to be creative.	24.3%	39.3%	15.9%	9.3%	9.3%
I think the things I learn in MSI are useful.	15.0%	32.7%	18.7%	18.7%	14.0%

Sophomore students enrolled in MSI (n = 107) were surveyed with questions modified from the HSSSE.

thus adjusting to a residential lifestyle, living away from home, and for many of them, taking challenging courses that now required them to study more frequently and, perhaps, differently.

Faculty Perceptions of MSI

It was a consensus decision of the science team to teach MSI and to reorganize the core science program. Overall, the feeling about the MSI course is positive, but there have been some challenges to overcome. Some teachers felt that there was too much emphasis on statistics. This was coupled with comments, however, that some individuals did not feel comfortable teaching statistics. We have seen that the students are more readily incorporating statistics into their independent investigations and applying statistics more readily in other courses. There has also been more conversation and sharing between courses, especially when students are using the same skills, such as linear regression analysis, in two courses. Students' graphing habits are improving, as are their writing skills.

Initially, there was some tension between scientific writing and writing a lab report. For scientific writing, students were documenting data, but were supporting their conclusions with summary statistics and the results of statistical analyses, not listing raw data and/or showing all calculations on raw data. Some content courses wanted lab reports with raw data. Consequently, some students became confused, and a few went so far as to tell the instructor that the instructor was wrong because students were taught something different in MSI! This was easily remedied by discussing with students various types of writing, even in science, and indicating when one type may be more appropriate or useful than another.

Student Transfer of Knowledge From MSI

During the second year of MSI, we were able to compare student transfer of skills taught in MSI because we now had a population of students where the juniors had taken MSI as sophomores, but the seniors had not. These students are together in elective classes. We also looked at the sophomores' abilities to transfer knowledge from MSI taught in the first semester to SIB taught in the second semester.

We asked whether there was a difference in the ability of juniors versus seniors to write a paper in scientific format. In the Molecular and Cell Biology (MCB) elective, students crossed two strains of the fungus *Sordaria fimicola*, which each produce different colored spores, and examined the meiotic recombinant patterns. They then were told to use the class data to write a scientific paper with no other prompts. After the papers were collected, teachers made copies, removed student names, and assigned each paper a number. A teacher not associated with the class scored the papers for elements found in a scientific paper, such as embedded citations and captions on tables and figures (Table 8, p. 51). The maximum score a paper could earn was 10 points.

We found a significant difference between the number of juniors (34.7%) compared to seniors (3.0%) who scored a 10 versus a 9 or less (χ^2 =11.539; df = 1; P < 0.001). We then tallied the scores on the rubric to see if there was a difference between the juniors and seniors, and we found a significant difference in their mean rubric scores (t = *3.08*; df = *80*; P < 0.01).

We also compared juniors to seniors with respect to each rubric item (Table 9). More specifically, we compared the number of juniors to the number of seniors who scored 2 points vs. 1 point or less on the rubric. Yates's correction for continuity was applied to these analyses. Whether students had divided their paper into sections delineating different parts of a scientific paper was dependent on class, with 82% of juniors compared to 54% of seniors doing so ($\chi^2 = 5.74$; df = 1; $P < 0.05$). Whether there was a table with a caption was also dependent on class. Fifteen percent of seniors included a table with a caption in their report, whereas 53% of juniors did ($\chi^2 = 10.49$; df = 1; $P < 0.01$). Significantly more juniors (59%) referred to the table in the text then did seniors (18%) ($\chi^2 = 8.36$; df = 1; $P < 0.01$).

Table 8. Scoring Rubric for *Sordaria* Paper

2	1	0
All sections of scientific paper present—introduction, methods and materials, results, discussion and conclusion	Some sections are present in paper	No discrete sections in paper
Literature cited section present and citations are complete	Literature cited section present but citations are incomplete	No literature cited section
References cited in text	Inconsistent citing in text	No references cited in text
Tables/figures with caption in results section	Tables/figures without caption in results section	No tables/figures present
Text in results section refers to tables/figures	Text present in results section, but does not refer to tables/figures	Only tables/figures included in the results section; no text present

Table 9. Comparison of Writing Skills of Juniors Versus Seniors

	Seniors (n = 33)			Juniors (n = 49)					
score	2	1	0	2	1	0	χ^2		
Paper had sections	54%	3%	42%	82%	6%	12%	5.74	P < 0.05	dependent
Literature cited section	82%	3%	15%	86%	0%	14%	0.03	P > 0.80	independent
References cited in text	63%	6%	30%	73%	6%	20%	0.50	P > 0.40	independent
Table present with caption	15%	57%	27%	53%	33%	14%	10.49	P < 0.01	dependent
Results text refers to table	24%	18%	57%	59%	12%	14%	8.36	P < 0.01	dependent

Scientific paper writing skills of juniors, who had taken MSI, and seniors, who had not taken MSI, in the same biology elective were assessed. The percent is of seniors and juniors scoring 2, 1, or 0 points on each rubric item for various elements found in a scientific paper. Chi-square results are for the test of independence with the variables being class (that is, juniors versus seniors) and score (2 versus 1 and lower).

Regarding a literature cited section with complete citations, there was no significant difference between juniors and seniors (χ^2 = 0.03; df = 1; P > 0.80). We also found no difference between the classes when it came to citing sources in the text (χ^2 = 0.50; df = 1; P > 0.40). These two skills are common for humanities and English papers as well as scientific papers, so there may also be transfer from other nonscience classes. Although we cannot conclude that MSI was the only factor that was responsible for the difference between juniors and seniors in their ability to write a scientific paper, we believe that it played a role in this difference.

Sophomores in SIB in their second semester who had taken MSI in the first semester were assigned to write a paper on a chromosomal abnormality. Each student was assigned a different syndrome (for example, Down syndrome, Edwards syndrome, or Patau syndrome). Besides the description of what information to include, students were only given the prompt to "use credible sources." They were not given any prompts about citing their sources in the text. All but 1 out of 71 students included a bibliography. Only 7% of the students had a mix of credible and noncredible sources, whereas 93% used only credible sources. Somewhat unsettling, however, was the fact that only 30% cited sources in the text. It appears that students are aware of what a credible source is in science, and that including a bibliography is part of writing a paper. Although all students were exposed to the idea of citing in text and were required to do so in MSI the previous semester, not all had internalized this as a habit.

Effect of MSI on SIR

Students are conducting more investigations that use human subjects. Three investigations in 2005–06, six investigations in 2006–07, and 14 investigations in 2007–08 were submitted by students to IMSA's institutional review board (IRB) for approval. These were studies where students wanted to collect data systematically using either surveys or some experimental treatment (for example, "What is the effect of music on memory?"). MSI incorporates survey design for data collection, as well as information about the use of human subjects in research and IRBs. It is possible, then, that this increase may be caused by the experiences of students in MSI. Students also understand the need for the "extra paperwork" when completing an IRB proposal because they have learned that it is a normal and required aspect of human subjects research.

We also believe that we are growing a culture of students who are more readily using statistics. These investigations, and many others in SIR, are incorporating statistical analyses of data in their final papers. Students actively seek out MSI teachers and the research office staff, for both on-campus and off-campus investigations, to determine which statistical test is most appropriate for their data.

We wanted to determine objectively the effect of MSI on SIR by examining SIR proposals or final papers for carryover of key elements of MSI such as use of statistics, embedded citations, quality of sources, and improved data presentation and writing skills. However, we feel that there are too many confounding and changing elements within SIR and our students to carry out solid analyses. The off-campus and the on-campus programs were merged together, with identical requirements and assessments for both groups of students. This has not always been the case. We have a couple of years of students where some have had MSI and participated in SIR, and others have not had MSI and participated in SIR. However, this is confounded by the fact that trying to compare juniors who have had MSI and are in the first year of SIR with seniors who have not had MSI and are in the second year of SIR is not valid.

Further, SIR became a graded course for the first time this academic year, since the on-campus and off-campus programs were merged. Students get a grade of fail, pass, or pass with distinction. The students who are enrolled may drop without penalty by the end of the first quarter. Previously, students could drop at any time without penalty. Participation in prior academic years was noted on the transcript, but completion did not carry the possibility of being noted as distinctive or extraordinary. Students who did not complete SIR successfully simply had the notation of SIR removed from their final transcript.

SIR Long-Term Outcomes

It is quite common for us to hear from previous students about the value of their IMSA research experiences and for students to tell us that they were able to obtain positions in college conducting undergraduate research, even in their freshman year. Anecdotes like the following two are quite common.

Anecdote Number 1

SIR made a huge difference for me. Mine was at Fermi National Accelerator Laboratory in 1993 at the birth of the Web, and my advisor (Matt Wicks) asked me to help him look at how to support various Web tools. This led me to learn how to program dynamic websites, which then jump-started my research career in college and graduate school because I was one of only a handful of people who had this skill. My research in graduate school ultimately turned into my company, MediaRiver. All of this would not have been possible without the opportunity offered by IMSA and the SIR program.

—Jay Budzik, IMSA class of 1995

Anecdote Number 2

I really think that my time in SIR helped me figure out what I want to do, and it is one of my most valued memories of IMSA. I wanted to let you know that I got the chance to enter an MD/PhD program, funded through the Growth and Development Training Program at the University of Chicago. I'm going to be getting a degree in cancer biology, and will be taking a leave of absence from med school to start the PhD next week! It happened really fast, but I knew it's what I wanted to do. I appreciate the opportunity to work with you at IMSA and that was a large factor in my decision to pursue a dual degree.

—Nan Sethakorn, IMSA Class of 2001

These are two very positive stories. Some students also relate that while the research experience was valuable to them, it showed them that they did not want to pursue the type of work that they had been conducting through SIR as a career. One parent related, "My daughter did an anthropology project in her junior year because she thought that was her career path. She soon changed her mind and did a botany project in her senior year and continues that work in college. We are so grateful to SIR." Even when an investigation turns out not to be as expected, most students still value the learning experience.

To address in a more objective fashion the effect of STEM research experiences on students' STEM education enrollment, we examined declared college majors and degree attainment for some of our IMSA graduates who had participated in SIR. Information on SIR participants was matched with data on student undergraduate enrollment and initial degree attainment. For the purposes of this investigation two classes were selected: the class of 2000 for initial degree attainment and the class of 2006 for initial college major. Discernable differences in both initial degree attainment and initial major in STEM versus non-STEM fields is evident when comparing graduates who engaged in STEM-based SIR experiences and those who did not.

Initial College Major for the Class of 2006

Of the 187 students in the class of 2006 for whom there was college major data available in the National Student Clearinghouse, 127 participated in SIR as juniors or seniors and 60 did not. The SIR students were further broken down by whether or not their SIR experience was in a STEM field or not. Students participating in multiple SIR experiences that did both STEM and non-STEM work are reported in the STEM group. Table 10 shows that the STEM SIR students went into initial STEM majors at a slightly higher rate than students who did not participate in SIR, and that students who had done SIR projects in the humanities or social sciences expectedly entered into a STEM major at a lower rate. This is not wholly unexpected given that early self-selection into a STEM field may be represented by student choice of SIR experience.

Table 10. Initial College Major by SIR Experience

	Initial Major					
Student Group	**STEM**		**Undeclared**		**Non-STEM**	
STEM SIR	74	76.3%	14	14.4%	9	9.3%
Non-STEM SIR	14	46.7%	5	16.7%	11	36.7%
No SIR	38	63.3%	8	13.3%	14	23.3%

Data on college major for the IMSA graduating class of 2006, n = 187, was obtained from the National Student Clearinghouse. STEM, non-STEM, and undeclared major data was correlated with participation in STEM or non-STEM SIR experiences.

Initial Degree Attainment of the Class of 2000

Using data from the National Student Clearinghouse, we were able to identify initial degree information for 105 members of the class of 2000, a match rate of 55%. Of those students, 54 had participated in SIR and 51 had not. Analysis of initial bachelor's degrees earned showed that students who had undertaken a STEM SIR experience were considerably more likely than non-SIR students to have persisted in attainment of a degree in a STEM field, 68% to 45%. Table 11 shows initial degree attainment by student SIR experience.

Table 11. Initial College Degree by SIR Experience

Student Group	Initial Degree			
	STEM Bachelor's Degree		Non-STEM Bachelor's Degree	
STEM SIR	30	68.2%	14	31.8%
Non-STEM SIR	5	50.0%	5	50.0%
No SIR	23	45.1%	28	54.9%

Data on college major for the IMSA graduating class of 2000, n = 105, was obtained from the National Student Clearinghouse. STEM and non-STEM Bachelor's degree attainment was correlated with participation in STEM or non-STEM SIR experiences.

While the near-term initial major data appear to show carryover from SIR experiences, the degree to which self-selection plays a role is probably strong. More interestingly, it appears that one of the residual effects of the SIR experience may be persistence in a STEM field, as is demonstrated by the data on initial degree attainment.

Discussion

The National Research Council (NRC) has emphasized the importance of teaching scientific inquiry in the National Science Education Standards (1996, 2000). According to the NRC (1996) scientific inquiry can fall into three categories. The first is the act of doing science. The second is that scientific inquiry can also refer to the way of teaching in the classroom in which students develop knowledge and understanding of scientific ideas. The third can be described as the nature of science, how scientists study the natural world. The thinking skills needed to perform inquiry are important for all students to have. The inquiry we describe in this chapter is the doing of science, often called authentic inquiry, although we do teach in an inquiry-based fashion and we do cover the nature of science.

When students do science, they take ownership of their learning and practice transfer of that learning as they solve problems that they find relevant. A National Science Foundation report (Russell 2005) assessed the value of undergraduate STEM research experiences as a positive predictor of continued career participation in STEM fields. The students surveyed indicated that the research experience helped them to plan and conduct a research project and assisted in their abilities to work both independently and collaboratively. Our data on IMSA graduates suggest that the SIR experiences that we are facilitating are supporting high school students in their STEM careers in similar ways. Our students are obtaining and continuing research experiences early in college and their high school research experiences are having an effect on their college major selection. We hope to ask similar questions of IMSA high school graduates to those that Russell did when assessing the value of undergraduate STEM research experiences.

SIR students are asked to reflect on their learning in SIR as part of their final papers. Although they encounter inquiry-based teaching in their science courses, overwhelmingly, students convey how different their learning experience is through SIR compared to their coursework. They find SIR to be more "real world" and, of course, more personalized because they have chosen the topic to explore and have gained a deep understanding of it. For a number of years, we have been providing substantial research opportunities to students, and those opportunities have been valued. However, as we have reflected on our teaching and learning and worked with our students in more personalized ways, we realized that we could improve their research experiences. To better prepare students for research, we changed our SIR program and developed MSI. Our beginning inquiry into the effects of MSI suggests that some of the objectives of the course are being transferred by the students into other courses and research experiences.

We continue to evaluate and modify our SIR program and the science courses based on our teaching experiences, perceptions of student learning, and by working in a very personalized way with our students. Our goals are to make continual improvements in students' acquisition of inquiry skills and scientific habits of mind.

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