

Student Inquiry at the Illinois Mathematics and Science Academy

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Setting

Located in Aurora, Illinois, the Illinois Mathematics and Science Academy (IMSA) is an internationally recognized, pioneering educational institution created by the State to develop talent and stimulate excellence in teaching and learning in mathematics, science, and technology (Marshall 2002). IMSA's advanced residential college preparatory program enrolls 650 academically talented Illinois students in grades 10–12. Students come from across the state of Illinois, applying as freshmen to enter the Academy in the sophomore class. The student body is 50% female and 50% male. Of the 2003–04 student profile, 69% of students were from the Chicago/Metropolitan area and 31% were from other areas of Illinois. Ethnic demographics for this group were 49% White, 35% Asian, 8% African American, 4% Latino, 3% bi-racial/multi-ethnic, and fewer than 1% Native American. IMSA utilizes an accomplishment-based selection process that incorporates performance on projects as well as participation or leadership in extracurricular activities, together with more traditional indicators of achievement, such as test scores and grades. Typically, 10–15% of the entering class will be eighth graders, although younger students have been admitted occasionally.

The *More Emphasis* Conditions

Student inquiry (Illinois Mathematics and Science Academy 2000) encourages students to be in charge of their own investigations, thus engaging them in a rich opportunity to emulate a practic-

ing scientist (Table 1). This approach allows them to learn scientific concepts in the context of inquiry, and not as isolated, unconnected facts. Since the inquiry investigations are focused on a question of the students' choice, students investigate a few fundamental scientific concepts in depth. As students work on their investigation, the scientific skills they learn are in the context of their question, so there is an inherent reason for them to learn the subject matter. Since investigations take place over a year, students reflect about how real science is done, rather than classroom science. The goal is for students to build a rich experience, to integrate their scientific learning into their conceptual understanding, and to learn important skills such as critical thinking, skeptical inquiry, and finding and evaluating information. Students employ skills in their investigation that are more complex than simple observations or inferences. When they design and conduct their own research, they draw conclusions based on generated evidence. Investigations do not necessarily come up with "correct" answers and frequently lead to more questions. Advisors and students share in the responsibility for learning, and advisors are continually assessing students' growing scientific understanding and reasoning. As the students become more experienced, they self-assess their understanding and take on more responsibility for their learning.

Table 1. The Student Inquiry Program at IMSA.

Started in 1998, the Inquiry Program (which actually encompasses all disciplines—mathematics, history and social science, foreign language and culture, fine and performing arts, as well as in the sciences) has steadily grown and investigations in the sciences have increased. The total number of investigations is cumulative of inquiry and senior research across all disciplines and junior/senior research in science. The number of investigations reflects unique investigations, some of which have more than one student working collaboratively on a project. Science investigations are inclusive of experimental studies, observational studies, computer science, the biographies writing project, and science education curriculum development; social science investigations were not included. Note that more females than males are pursuing scientific investigations.

School Year	98–99	99–00	00–01	01–02	02–03
Investigations	30	48	45	66	74
Total Students	50	96	102	133	127
Student in Science Investigations	19	36	53	66	76
Students in Nonscience Investigations	31	60	49	67	51
Male	42%	44.8%	47.1%	45.1%	44.9%
Female	58%	55.2%	52.9%	54.9%	55.1%

Teachers, Students, and Inquiry at IMSA

Students conducting inquiries are advised by Academy faculty and staff members, who do so on a voluntary basis. Of the entire IMSA faculty, all have a minimum of a master's degree, with 38% holding a doctorate. Of the fourteen science faculty, seven hold doctorates, five are NBPTS certified, and most have research experience. The Coordinator of Student Inquiry holds a doctorate in science and oversees the entire program; she does not teach any formal classes at the Academy. She directs the Grainger Center for Imagination and Inquiry (GCII), which is approximately three thousand square feet of space designated for student investigations in the laboratory as well as general inquiry support. For most students, inquiries are pursued during their unscheduled time and on "inquiry Wednesdays," a day at the Academy without scheduled classes. The exception to this schedule pertains to students who are enrolled in the Junior/Senior Research in Science course. They have time allotted for this work in their schedules and are expected to pursue their work on inquiry Wednesdays as well. Investigations begin in August, when students return to the Academy, and culminate in a public presentation of their work in late April.

Student Inquiry in Science at IMSA

Student Inquiry in Science at IMSA is an in-depth and actively pursued study of topics reflecting student interests. The self-directed student plan of inquiry is a progression of learning experiences that is designed and conducted in response to a student's (or a group of students') questions. Students pose a specific question or problem and strive to answer it through carefully focused study. The knowledge generated helps students gain a deeper understanding of the topic of their interest.

The role of the *advisor* is to support and guide the student in pursuit of the inquiry. The advisor, an IMSA staff or faculty member, is usually experienced in the particular subject area, or interested in the topic, so that he can thoughtfully guide the student in content specifics as well as process.

The investigation begins by formulating a *proposal* or plan of inquiry. The inquiry advisor and the Coordinator of Student Inquiry review the student's proposal, which includes discussion of sufficient depth to explain the investigation, as well as discussion of the potential ethical implications of the work. The investigation that is carried out is documented through a journal or notebook. A formal progress report or abstract of the work is written each semester to assess progress of the study and to allow for reflection on the investigation. Public communication of work for peer review and discussion is an important part of every inquiry. Presentation Day at IMSA, each spring, provides a forum where all those completing Student Inquiry and Research offer their work to the IMSA community, guests, and parents via a formal fifteen-minute oral presentation, including questions. A final report and reflective discussion with the inquiry advisor completes the inquiry investigation.

Students may pursue an Inquiry investigation through three different pathways. These options are the *Student Inquiry Program*, *Senior Research (SR)*, or *Junior/Senior Research in Science (JSR)*. Most students successfully completing an inquiry investigation receive notation on their IMSA transcript, but do not receive a grade or graduation credit.

Senior Research is an inquiry investigation that has continued into its second year. Only seniors who have successfully completed one year of inquiry are eligible. It counts as 0.5 credits per semester and students complete the same requirements as for the student inquiry program. Senior Research receives a pass/fail grade, but SR does not count in the course requirements for graduation. Some students who have reached course enrollment limitations will pursue a second year of investigation as student inquiry rather than senior research (with successful completion noted on their transcript).

Junior/Senior Research in Science is a one-year long, credit-bearing course offered for the first time in the 2002–03 school year. The requirements are the same as for student inquiry and SR. A major difference, however, is that students have time allotted in their course schedule, and an instructor, as part of his teaching load, has been designated to work with the students. Students receive a letter grade for JSR and it can count toward graduation requirements.

Inquiry Proposal

The *inquiry proposal* serves to plan and focus an inquiry investigation. Key to the inquiry is a *focusing question* that the student develops and commits to pursuing. This question is developed by the student in response to passion, curiosity, and interest, and is based on what is known about a particular subject. Marbach-Ad and Sokolove rank questions from “simple” to those that are “academically grounded” and admit of being investigated (Marbach-Ad and Sokolove 2000). We are striving for questions that are formed and answerable using multiple sources. While students may want to make or build something, such as a fuel cell or terrarium, “Can I make ... ?” or “Can I build ... ?” is not a sufficient question because it doesn’t encompass a scientific investigation—and it has a “yes or no” answer. Rather, a question such as “What components are critical to constructing an efficient fuel cell?” is better, and the resulting investigation contains elements that can be modified and changed for experimental data collection.

The *project description* serves to document background knowledge and to describe, in detail, the strategy for implementing the inquiry in the context of what the student knows. The description should declare what is known about the subject of the inquiry and how one got to the point of wanting to carry out the work.

The background research for the inquiry is documented by a *bibliography*. The listed bibliography may also include materials that have been identified for use as the inquiry progresses; it will change and grow depending on the path the inquiry takes. As the inquiry develops, the bibliography should reflect use of more primary sources as knowledge deepens and as the inquiry grows and becomes more meaningful and sophisticated.

The inquiry proposal includes a *research plan*. This is a timeline that includes biweekly benchmarks for accomplishment. This plan will help the student define the work to be accomplished in order to answer the focusing question. It should help determine whether what the student intends to do can actually be accomplished. It will also help to determine whether the project’s intended goal (and perhaps its focusing question) is changing based on the work. The research plan documents a regular schedule for meetings with the inquiry advisor for substantive discussion of the investigation. The plan will also expose potential safety issues at the start of the investigation.

Research studies have the potential to affect the human condition and society. Analysis of the *ethical* and *societal* aspects of the work assists the student in moral growth, places a social perspective on the work, and helps ensure that no one is harmed. Students should fully and carefully state and discuss the work they are undertaking, and how the topic has affected society in the past or may affect society in the future.

The Investigation

Students determine the course of their investigations. They must find time in their schedule to do the work and meet with their advisors. It is expected that they will meet with their advisor at least every “inquiry Wednesday” to discuss what has and has not been done. This meeting may be brief if little has been accomplished or if work is “routine.” It may last for several hours if data is being analyzed and discussed or if roadblocks have been encountered. Inquiry Wednesdays are also used for the actual hands-on laboratory work in the GCII and other facilities, as well as field observation and consultation with other experts in the area. Laboratory work is rarely completed on a single day, so students also work after school and during class breaks in the regular school day.

Inquiry Journal

Documentation of one’s work and the journey that was taken to arrive at a particular conclusion or final product is important in constructing the meaning of the work. It assists in providing a basis for replicating, developing, and polishing further efforts. A journal provides a way to keep a record of specific work accomplished or to record the

path of failure; both can be built upon. Additionally, an inquiry journal can be used to record reflections and thoughts of possible paths that may not be pursued immediately. A good journal will include notes from discussion with an advisor or other individual who has helped the investigation, notes and excerpts from the literature that serve to guide the inquiry, protocols followed, and results, observations, data analyses, and questions for further thought and investigation.

Progress Report

Near the end of the first semester of an inquiry, students document and reflect on their projects by preparing a progress report. One page is usually sufficient to discuss what has been accomplished and where the inquiry is going. It should include a brief discussion of problems that have been encountered and where the investigation has gone. Has the focusing question changed?



Students perform hands-on laboratory work during “Inquiry Wednesdays.”

Additions to the bibliography should be included. The report should include any data, analysis, and observations that document successes and challenges. A well-maintained inquiry journal should facilitate the writing of the progress report.

Presentation of the Investigation

Public presentation and discussion of one's work or work-in-progress is standard in the academic community. The discussion that follows the presentation is beneficial to the academic community as a means of constructing understanding. Work that is conducted is certainly valuable to the investigation, but inviting scrutiny by peers and the community shares what has been learned and allows others to use it as well and to offer critiques. Critique is a useful means to gauge learning and a springboard for further productive investigation. IMSA offers Presentation Day in the spring, when students participating in Student Inquiry and Research present their work orally.

Each year, IMSA publishes a Presentation Day *abstract* book. Individuals attending presentations use the book to determine which talks they would like to attend. The abstract, therefore, should provide a summary of the key accomplishments and information that the listener will hear about in the presentation.

Oral Presentation

Students at IMSA are expected to speak with power, economy, and elegance (Illinois Mathematics and Science Academy 1999). The oral presentation of their inquiry investigation demonstrates these skills while communicating highlights of what has been accomplished and learned. Students are allotted fifteen minutes on Presentation Day to exhibit their work to others, with talks moderated by IMSA faculty and staff. The talk is organized so that the student speaks for ten to twelve minutes and allows three to five minutes for audience questions. Because we plan Presentation Day for the end of April each year, some students will not complete their investigation in this time period. Even so, they must still present their work-in-progress, discussing accomplishments, learning, and the next steps.

One week prior to Presentation Day, a formal, required practice day is scheduled. This gives students the opportunity to test and use presentation equipment while practicing their presentations. Staff moderators use practice day to provide feedback to the students on both presentation content as well as the students' speaking skills. Practice day is critical to good oration and forces students to plan instead of leaving the preparation to the last minute. This gives students another week in which to polish their talk and modify content. Many will practice again with their advisor.

Final Paper

A final paper, in the form of a scientific report, is expected of each investigation. Draft papers are collected about two weeks prior to Presentation Day. This process assists students in preparing their oral presentations and serves as a formative assessment. The advisor provides comments and feedback for improving the final paper, which is due about two weeks after Presentation Day.

One aspect of the final report asks the student to consider and reflect, in a metacognitive fashion, on the inquiry experience itself. What did the student learn about learning? How is this different from science class? Where did the investigation start? Where did it go? What answers were found? What answers were not found? What did the student learn and accomplish? How is that learning valued and valuable? What was learned about inquiry and directing one's own learning? These are the questions that one should consider when reflecting on the inquiry investigation.

Reflection with Advisor

Following Presentation Day, and after completing the requirements for inquiry, the student and advisor also discuss the process of the investigation and what has occurred during the course of the Inquiry. This is a critical examination of the learning experience, where both student and advisor reflect on accomplishments and on how improvements could have been made. It is intended to provide for growth in further learning. Any deficiencies or lack of quality in requirements are addressed, and determination made as to whether the deficiencies (if present) are serious enough to drop the inquiry from the transcript, with no penalty to the student.

Student Learning

Communication, discussion, and defense of one's learning are powerful ways to demonstrate authentic learning through inquiry. For this reason, students are required to present their work on Presentation Day to IMSA staff, guests, and peers. We do not want students to fail on Presentation Day and neither student nor advisor wants to be embarrassed by a poor presentation, so the formative assessments (progress report, abstract, journaling, discussions) are very important to a successful inquiry. Some self-selection by the student about accomplishment and learning occurs prior to presentation and some inquiries are dropped during the year. The advisor and Coordinator of Student Inquiry also speak throughout the year about what the student has been doing and accomplishing, and intervene if work is not being done. Sometimes students are encouraged to drop the inquiry, primarily because the student has taken on too many other activities or responsibilities in addition to the rigorous academic course requirements of the Academy. Sometimes the student is just not doing the work needed, or has lost interest in the inquiry. The advisor plays the largest role in determining whether the student has accomplished sufficient learning, but advisor expectations can differ, making the determination subjective. One makes an assumption that all of those students presenting on Presentation Day have met minimal program requirements.

Objective demonstration of learning is most clear when students are able to present or publish in peer-reviewed venues, as has been the case for some students in inquiry. Fifteen students each wrote a biography of a living American scientist, based on personal interviews and background research. Prometheus Books published *Portraits of Great American Scientists*, edited by L. M. Lederman and J. A. Scheppler, in 2001. (Fourteen students are writing a second book.) A few students have authored or co-authored journal articles (Agarwal 2001; Malina and Young 2002; Scheppler, Sethakorn, and Styer in press).

Scientific meetings are important presentation venues, both those that are strictly for students as well as those for professionals. Our students regularly present at the Illinois Junior Academy of Sciences (IJAS) and the National Consortium of Specialized Secondary Schools in Mathematics, Science, and Technology (NCSSSMST) Student Research Symposium. IJAS and NCSSSMST provide an opportunity for students to present to, and interact with, peers external to IMSA, as well as to speak about and to defend their work before an audience of knowledgeable professionals. We also look for safe and nurturing opportunities where students can present at professional conferences. These opportunities have occurred at the national meetings of the American Society of Microbiology, the National Association of Biology Teachers, and the Society for Integrative and Comparative Biology. Regional meetings, such as the Illinois Section of the Mathematics Association and the Illinois State Academy of Sciences have proven appropriate presentation venues for our young scholars. Siemens Westinghouse Science and Technology Talent Search and the Intel Science Talent Search are two well-known competitions to which IMSA students often submit work.

Presentations at professional conferences, reviewed publications, and juried venues provide good standards for student work. In reality, this happens for a small, but significant, number of students each year. What about the rest of the students and their work? This has been something that we have grappled with for the entire five-year history of the inquiry program. “I know it when I see it” is a common phrase heard in discussions of inquiry quality and student learning. Part of the difficulty lies in the wide variety of investigations that students pursue. There are also many different advisors involved in the program, and both the students’ abilities and the advisors’ knowledge vary. Part of the assessment consists in whether students have completed all of the requirements: proposal, discussion of ethical and societal implications, progress report, abstract, presentation, and engagement in the work in a satisfactory way.

To better define a reliable assessment of student inquiry performance and learning, standards for inquiry have been drafted (Table 2). It is expected that these standards will guide focused discussions between students and staff in helping to assess learning. The standards are centered on planning, investigating, analyzing, and communicating the investigation. We emphasize, however, that this process is not a linear one. For example, students are expected to continually review scientific literature for research that relates to theirs. They may move back and forth many times between investigation and analysis, modifying protocols or selecting alternative ones. A conclusion may lead the student along an entirely different path than originally intended, resulting in the development of a new focusing question and the need to delve into different scientific literature.

We undertook a retrospective analysis of the past two years’ worth of science inquiry investigations. These years were chosen because the inquiry program is continually evolving. Investigations were assessed (Table 3) using a framework for evaluating inquiry tasks (Chinn and Malhotra 2002), designed to determine the degree of similarity between school inquiry investigations and authentic science.

As discussed earlier, all investigations, even writing investigations, must have a research question; also, the students’ work must be academically grounded in the professional literature, so these two characteristics were present in all investigations.

Table 2. Inquiry Standards—Plan, Investigate, Analyze, Communicate

For the purposes of developing standards, an Inquiry investigation was broken down into planning, investigating, analyzing, and communicating. One should note, however, that Inquiry is not a linear process. As the Inquiry progresses, you will return to primary and secondary sources, looking for new connections or newly produced research by others. You will move back and forth between investigation and analysis as you progress in your work, using what you have done to refine your focus and your work, and to move forward. You will continually plan, work safely, and determine whether you need more materials. Discussion and communication with your advisor and colleagues is ongoing.

PLANNING

- A. Students engaged in inquiry construct viable inquiry questions
 - The question exhibits a focus for the student's curiosity
 - The question is compelling and complex for the student
- B. Students engaged in inquiry conduct scholarly background research
 - The student uses multiple and appropriate primary and secondary sources
 - The student evaluates the credibility of the source material
 - The student creates a bibliography
- C. Students engaged in inquiry organize and plan their investigation
 - The student states potential outcomes
 - The student schedules and plans work
 - The student addresses safety issues where appropriate
 - The student acquires all necessary materials
- D. Students engaged in inquiry address implications of the investigation
 - The student addresses ethical implications of the investigation
 - The student discusses societal implications of the content of the investigation

INVESTIGATION

- E. Students engaged in inquiry use appropriate procedures and methods
 - The student assesses risk of the procedures and works in a safe manner
 - The student makes multiple observations/examines varied evidence
 - The student selects variables/critical parameters
 - The student develops controls/calibrate instruments, where appropriate
- F. Students engaged in inquiry document the inquiry in a journal
 - The journal contains a record of data and observations
 - The journal contains a detailed record of the methods used
 - The journal contains a record of sources and an annotated bibliography
 - The journal documents discussions of the inquiry with advisor and others
 - The journal documents the student's thinking
- G. Students engaged in inquiry meet face-to-face, at least weekly with the inquiry advisor
 - The student discusses and demonstrates progress
 - The student discusses difficulties and possible solutions

ANALYSIS

- H. Students consider relationships among components of the inquiry
 - The student identifies the components
 - The student organizes the components into coherent and cohesive form
 - The student averages and graphs data if appropriate
 - The student performs statistical analysis where appropriate
 - The student conjectures relationships where appropriate

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- The student constructs arguments based on information
 - The student compares the inquiry to work by others
 - The student builds systematic arguments or synthesis
- I. Students engaged in inquiry draw and defend conclusions
- The student considers the limitations of the methods
 - The student discusses uncertainty, if appropriate
 - The student considers the contribution to the field
 - The student reconsiders ethical and societal implications

COMMUNICATION

- J. Students engaged in inquiry orally communicate their investigation to the public
- The student uses good oratory and presentation skills
 - The student conveys concise summary and significance
 - The student uses appropriate visual aids
 - The student balances evidence and discussion
 - The student fields questions well
- K. Students engaged in inquiry communicate their investigation in written format
- The paper is grammatically and mechanically correct and discipline appropriate
 - The paper is complete and thorough—see discipline specific paper guidelines
 - The paper contains an abstract
 - The paper contains appropriate visual resources
 - The paper contains complete appropriate bibliography, references, or footnotes
 - The paper contains an appendix or addendum as needed

Not all investigations will contain all of the characteristics of authentic inquiry, and this framework is most applicable to investigations where experiments are conducted. For example, our students often pursue writing projects, develop science education curriculum, and do engineering and technology design, so in these investigations students do not select variables, develop controls, observe intervening variables, and so forth. These investigations are still important to students gaining real-world science experiences.

Summary

The Student Inquiry Program at IMSA provides students with opportunities to conduct long-term investigations of their own design. Many of our students have preconceived expectations of science from their course work. The fact that students pursue their work on Inquiry Wednesdays, during free time, and utilizing the GCII, deliberately places their work in a different context from the classroom, therefore it is closer to “real” investigation, and students think about it differently. Acceptable investigations cover a wide range of scientific work, including the writing of scientists’ biographies, field observations, and technological design, as well as experimental research.

Students are capable of carrying out high quality work, especially when the work is exciting and interesting to them. Educators must, therefore, set a high standard and create the conditions for student success. The Student Inquiry Program at IMSA provides one way in which students can conduct authentic inquiry investigations, striving for the high quality and real science experiences that the National Science Education Standards demand.

Table 3. Science investigations with features of authentic inquiry

Science investigations from 2001–02 and 2002–03 were evaluated as to whether the investigation exhibited the features of authentic inquiry, described by Chinn and Malhotra (Chinn and Malhotra 2002). The 52 investigations were conducted in the groups: inquiry, senior research, or junior/senior research in science.

<i>Characteristic</i>	<i>% of projects (52 total) with characteristic</i>
Generating research questions	100 %
Selecting variables	61.5%
Developing simple controls	51.9%
Developing relatively complex controls	11.5%
Making multiple observations	55.8%
Observing intervening variables	9.6%
Using analog models	46.2%
Simple transformation of observations	63.5%
Complex transformation of observations	5.8%
Consideration of methodological flaws	44.2%
Developing theories and mechanisms	23.1%
Multiple studies of the same type	61.5%
Multiple studies of different types	9.6%
Studying expert research reports	100 %



The Student Inquiry Program allows students to develop a proposal, perform a long-term investigation, present their findings to faculty and classmates, and write up a formal scientific report.

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