

# The Learning Story of the Illinois Mathematics and Science Academy

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## Context

In a 1998 *Chicago Tribune* interview with Mary Catherine Bateson, anthropologist, author and daughter of Margaret Mead and Gregory Bateson, Ms. Bateson was asked, “How does a parent today prepare a child for a future world that is difficult for that parent to imagine?” (Schreuder, 1998, p. 2).

Ms. Bateson replied, “Suppose you knew that your child would be part of a group that went to form the first colony on another planet, how would you prepare this child for life there? That’s the kind of thing we should be asking ourselves about education. You can’t prepare the child for the job market that will exist 20 years from now. So how can you build a curriculum that will shape an individual to be a pioneer in an unknown land - because that’s what the future is...” (Schreuder, 1998, p. 2).

Reflective educators have long been asking this question; but never has the need for a response grounded in new insights about human learning and the transformation of the traditional structures of schooling been more essential. The quality of our future is inextricably connected to our capacity for knowledge acquisition, knowledge generation and continuous learning; these capacities will be the new measure of “wealth” and “wealth creation” in the knowledge era.

## Introduction

This paper is a story.

It is the story of a relatively young institution, the Illinois Mathematics and Science Academy (IMSA). The story describes what we are doing to design a learning environment that develops and nurtures intellectual and creative talent primarily in mathematics and science. We want our students to be able to invent what we call ‘a new mind’ and facilitate that process through the creation of an intellectually rigorous, thoughtful, imaginative and reflective learning community that liberates the goodness and genius of all children and invites and inspires the power and creativity of the human spirit for the world.

It is also the story of an experiment in learning; a ‘work in progress’ that seeks to understand and clarify the relationships between intentionally designed learning experiences that are competency-driven, inquiry-based, problem-centered and integrative; the capacity of a learner to create a more integrative and reflective mind; and the ability

and desire of learners to imagine and then work to create a compassionate and sustainable world that works for everyone.

It is our belief that there is a profound connection between the world we wish to create, the mind needed to create it and the learning environment and learning experiences we create for children by design. It is this belief that drives us to engage in the work required to resolve two critical questions:

- What is the nature of the learning paradigm that must ground our knowing for a new and sustainable global community?
- What learning conditions enable this new paradigm of learning to become manifest in schools in order to make generative and integrated understanding more likely?

IMSA's story is our journey into the exploration of these questions.

### **IMSA's Creation and History**

Co-founded by Nobel Laureate Dr. Leon Lederman and the former Governor of Illinois James R. Thompson, the Illinois Mathematics and Science Academy was established by the Illinois General Assembly in 1986 as the United States' first three-year public residential learning laboratory for high school age students with demonstrated talent and potential for mathematics and science. Currently 650 academically talented students from throughout Illinois attend the Academy for 3 years (grades 10-12); admission is highly selective and there are no fees for tuition or room and board. The Academy is also required to serve as a catalyst to stimulate improvement in the teaching and learning of mathematics and science for all Illinois students and teachers.

Despite the uniqueness of our student population and learning environment, I invite you to transcend these contexts and apply the learning principles described to the creation of any learning environment designed to develop and nurture critical and creative thinking, intellectual rigor, curiosity, imagination, and authentic engagement with fundamental concepts and transdisciplinary questions that immerse the learner in significant real-life dilemmas.

### **IMSA'S Mandate and Challenge**

The Illinois Mathematics and Science Academy is charged to create an exceptional learning environment for our students and to advance teaching and learning in mathematics and science in Illinois and beyond. This latter mandate is the most challenging. Although we offer systemic professional learning experiences for Illinois teachers grounded in our beliefs about human learning and designed around our core competencies (learning experiences that are competency-driven, inquiry-based, problem-centered and integrative), we do not control the learning conditions in other schools. Nonetheless, both our experience and our research support the belief that all students will

achieve at significantly higher levels of disciplinary and interdisciplinary understanding and will learn how to engage in the doing of real science, *if* learning experiences are intentionally designed to enable them to do so.

## **New Design Principles for Learning**

The last decade has produced remarkable new insights about human learning. It is our belief that if we want to develop self-directed, inquiring, collaborative, and courageous pioneers, we must create learning conditions based on these principles derived from our emerging understandings of cognition (mind) and neuroscience (brain).

Although our current knowledge about the structural development and neural functioning of our brain is insufficient to definitively use it to create learning conditions, there does seem to be an emerging set of “brain/mind” principles that can inform our thinking. Formulated by Caine and Caine (1996, p. 2-4), these principles, “serve as prisms for integrating research in many fields and guiding the ways in which we think about the brain...” [and]...these principles serve to bring to educators at least 12 coherent factors that reliably and with integrity describe learning...”.

What are these brain/mind principles?

- 1. The mind/brain is a complex adaptive system; thoughts, emotions, imagination and predispositions operate concurrently.*
- 2. Learning engages the entire physiology; there is a direct relationship between our physiological functioning and our capacity to learn.*
- 3. The search for meaning is innate; the brain resists having meaninglessness imposed on it.*
- 4. The search for meaning occurs through patterning; learners construct meaning through creating patterns of connections.*
- 5. Emotions are critical to patterning; emotions and thoughts shape each other and cannot be separated.*
- 6. Every mind/brain simultaneously perceives and creates parts and wholes; in a healthy person, both hemispheres interact in every activity.*
- 7. Learning involves both focused attention and peripheral perception; the brain absorbs information of which it is directly aware, but it also directly absorbs information that lies beyond the immediate focus of attention.*

8. *Learning always involves conscious and unconscious processes; because entire experiences are processed, understanding may occur well after information was experienced.*
9. *The mind/brain organizes memory in at least two different ways (spatial memory system and a set of systems for rote memory).*
10. *Learning is development. Development occurs in several ways. In part, the brain is 'plastic'; much of its 'hard wiring' is shaped by experience.*
11. *Learning is enhanced by challenge and inhibited by threat. The brain learns - it makes maximum connections optimally when appropriately challenged, but 'downshifts' under perceived threat.*
12. *Every mind/brain is unique; there are different learning styles, talents and types of intelligences.*

These brain/mind principles, reinforced by the Learner-Centered Psychological Principles created by the American Psychological Association (Lambert and McCombs, Eds., 1998) provide a compelling set of constructs that inform how we can design learning environments that accelerate our natural learning process.

Such environments will enable learners to:

1. Direct their learning toward greater rigor, complexity, coherence, and integration.
2. Increase their intellectual, social and emotional engagement with and responsibility toward other faculty and fellow students, around questions of genuine significance.
3. Engage in collaborative, problem-centered and inquiry-based learning that develops integrative ways of knowing and transdisciplinary connections.
4. Participate in the world fully because they are 'fluent' in multiple 'languages' -- the languages of science, mathematics, poetry, music, nature, dance, arts and history.

In the absence of these skills, children are learning-disabled in a knowledge and information driven world; they will not be able to 'invent' the integrative mind required to advance the human condition in the 21<sup>st</sup> Century.

### **Curriculum: Core Competencies and Goals**

IMSA's curriculum is a coherent and integrated body of knowledge and skills that actively engages students with the understandings and insights of disciplinary and interdisciplinary knowledge. Its coherence is derived not only from the structure of the disciplines, but also

their consilience. It is also grounded in the Institutions's beliefs, philosophy, vision and mission.

IMSA's philosophy - to teach each child as if he/she is capable of significantly influencing life on the planet, its vision - to liberate the goodness and genius of all children for the world, and its mission - to transform mathematics and science teaching and learning by developing ethical leaders and integrative thinkers, all serve as boundary 'membranes' of our curriculum and approach to learning.

The Academy's curriculum is designed to be competency-driven, inquiry-based, problem-centered and integrative and it focuses on critical and creative problem-finding and problem-solving with four primary goals:

1. To develop intellectual potential, academic achievement, creativity and responsibility in all students.
2. To approach mathematics and science as the products of human creativity and curiosity.
3. To foster interdisciplinary approaches to thinking and learning by integrating the study of mathematics and the natural and social sciences with the arts and the humanities.
4. To practice what we call 'apprentice investigation' appropriate to each discipline.

The Illinois Mathematics and Science Academy's commitment to a curriculum devoted to inquiry, problem-centeredness and integration is grounded in our belief that integrated ways of knowing can only be nurtured in a learning environment that fosters the 'interrogative mood.' Or, in the words of Michael Casey (personal communication, 1989) of IMSA's English faculty:

*If we are to develop ways to make active student discovery happen, take hold and endure, we must define who we are in the classroom. A teacher who facilitates discovery, who creates the environment that makes discovery possible must realize it is not an environment out there for them the students but that the interrogative mood includes the teacher as well.*

*It is not enough to ask questions that evoke responses. One could do that all day and cover nothing but fact. The teacher must raise questions that genuinely puzzle the asker.*

*Facilitating discovery is the ultimate intellectual exposure because the way to encourage thinking is to be thinking yourself.*

The primary focus of the Academy's program is to develop thoughtful inquirers, ethical leaders, and responsible stewards. While much of our instruction occurs through in-class seminars and laboratory experiences, significant learning and research takes place outside of the geographic boundaries of the Academy. One day per week approximately 25% of

the student body (150 students) voluntarily leave campus for a full day and are engaged in a formal mentorship experience with renowned scientists, mathematicians and experts in other disciplines.

This yearlong research experience culminates in a formal on-campus presentation day where the students (with their mentors present) describe their research. Students not choosing to participate in this program are engaged in their own (preapproved) Plan of Inquiry, interdisciplinary seminars, or independent study. Approximately 60 students are annually invited to present their research in prestigious national and international research conferences.

Through these learning experiences, students are actively engaged in knowledge generation as well as knowledge acquisition. They are collegial researchers and equal partners; they experience the joy of discovery and the disappointment of failure. They learn the power of possibility, in following a question wherever it leads and in figuring things out. They are honored and respected for their talents and their questions.

IMSA is striving to design a learning environment that provides a forum for risk, novelty, experimentation and challenge and that gives power, time and voice to student inquiry and creativity. This learning environment is grounded in IMSA's Standards of Significant Learning (SSLs).

### **Standards of Significant Learning:** **Developing the Integrative Mind**

IMSA's curriculum is designed to enable students to demonstrate growth on what is called Standards of Significant Learning. These standards represent and provide evidence for the presence of those habits of mind that we believe contribute to integrative ways of knowing; we expect these ways of knowing to broaden and deepen over time.

An enumeration of the SSL's follows:

#### **I. Developing the Tools of Thought**

- A. Develop automaticity in skills, concepts, and processes that support and enable complex thought.
- B. Construct questions that further understanding, forge connections, and deepen meaning.
- C. Precisely observe phenomena and accurately record findings.
- D. Evaluate the soundness and relevance of information and reasoning.

## **II. Thinking About Thinking**

- A. Identify unexamined cultural, historical, and personal assumptions and misconceptions that impede and skew inquiry.
- B. Find and analyze ambiguities inherent within any set of textual, social, physical, or theoretical circumstances.

## **III. Extending and Integrating Thought**

- A. Use appropriate technologies as extensions of the mind.
- B. Recognize, pursue, and explain substantive connections within and among areas of knowledge.
- C. Recreate the ‘beautiful conceptions’ that give coherence to structures of thought.

## **IV. Expressing and Evaluating Constructs**

- A. Construct and support judgments based on evidence.
- B. Write and speak with power, economy, and elegance.
- C. Identify and characterize the composing elements of dynamic and organic wholes, structures, and systems.
- D. Develop an aesthetic awareness and capability.

## **V. Thinking and Acting With Others**

- A. Identify, understand, and accept the rights and responsibilities of belonging to a diverse community.
- B. Make reasoned decisions that reflect ethical standards, and act in accordance with those decisions.
- C. Establish and commit to a personal wellness lifestyle in the development of the whole self.

## **Mathematics and Science as Integral to the Human Experience**

As we continue to develop our program, we are acutely aware that decisions about curriculum, instruction and assessment are fundamentally decisions about the kind of minds we give our children the opportunity and invitation to create. If we are serious about solving the problems that plague us as a global community, we must invite our students to create the kind of mind that can identify and resolve these global human problems.



This is especially critical in mathematics, science and technology education. Although mathematicians and scientists who have developed mathematical power and a scientific frame of mind understand the beauty, elegance, and symmetry of mathematics as a pattern language and know science to be a window to the wonders of the universe and the natural world, these understandings of and orientation to mathematics and science are foreign to most students. We believe that the reason this is so, is the antiseptically rational and narrow (algorithmic) approach to mathematics and science that permeates most classrooms, emphasizing information accumulation, while isolating the students from the essential questions, perplexities and wonders of the natural world.

It is no secret that it is possible to receive the highest score possible on a national standardized mathematics or physics exam and still not deeply understand basic concepts of the physical world. Although many high school students in the U.S. graduate with presumed disciplinary mastery, there is growing evidence to suggest that they also graduate with thinking that is characterized by stereotypes, misconceptions, unexamined assumptions and rigidly held algorithms that inhibit their achieving genuine and deep understanding.

Mathematics is the universal language of science. It is a language of patterns and relationships as well as a discipline that explores relationships among abstractions. Students must perceive mathematics as part of the scientific endeavor. They must comprehend the nature of mathematical thinking, they must become familiar with how mathematical knowledge is constructed, and they must understand what drives mathematical inquiry.

Mathematics is a language of symmetry and interconnection, but students view it as linear and discrete. Mathematics is a form of abstraction, of symbolic transformation and application, but students view it as a process of memorization and computation.

As children, we don't begin our exploration of relationships of the natural world in this way. At a deep and fundamental level, every child is born a scientist. Unfortunately, the mathematics and science taught in most of our schools diminishes our natural capacity for inquiry and exploration. We must continuously rekindle students' inquisitiveness about the natural world by creating learning experiences that connect them to its wonders.

Within the framework of exploration and discovery in mathematics and science, students must be able to understand them as 'languages' and as 'ways of knowing,' whose knowledge base, symbol systems and concepts can enhance the understanding of other disciplines and other forms of knowing. Students must become 'multi-lingual;' they must be able to translate and use the symbol systems of one discipline to understand the complexity of others. If they don't, they simply will not have the tools for knowledge generation in the 21<sup>st</sup> century.

Based on its beliefs, philosophy, vision and mission, IMSA chose, by design, to create learning experiences in math and science that connect students to the elegance of mathematics and the wonder of scientific inquiry and discovery.

I want to offer you an example of how the context of a ‘mathematical caste of mind’ can be encouraged through other disciplines, by describing an example of an assignment given by Bernard Hollister (personal communication, 1990) an IMSA social science instructor. The assignment is called ‘The Story of an Equation,’ and this is what was presented to the class.

*In this activity you are going to be asked to develop an equation that sums up in a mathematical way, just what civilization was.*

*Historians are in rather general agreement that once humans ceased being hunters and gatherers and became farmers and herders, that the first great revolution in homo sapiens’ life-style took place – civilization.*

*As you know, humans and nature have a love-hate relationship. Some scholars have argued that all of historical time has been one of struggle by humans attempting to master nature. There has been heated debate over just what is the interplay between technology, population, population growth, the importance of urbanization, change in general and other factors, and just how they ‘equaled’ civilization.*

*It is your task to develop a working equation for the birth of civilization that will explain the relationship of these factors to the emergence of civilization. And here are the factors...*

*‘C’ is Civilization  
‘T’ is Time  
‘C’ is Change  
‘TC’ is Technology  
‘P’ is Population  
‘A’ is Area  
‘E’ is Energy  
‘Ag’ is Agriculture*

The students were given the opportunity to add any other variables that they found appropriate. The results of this assignment were fascinating. Some of the variables the students added included:

*‘G’ – Stability and effectiveness of the government  
‘Q’ – Quality of the lives of people  
‘SB’ – Shared Beliefs  
‘ES’ – Environmental Stress*

'CM' – Creative Minority  
'Cu' – Culture  
'UM' – Unwashed Masses  
'R' – Religion  
'ME' – Morals and Ethics  
'E' – Education  
'H' – Health

The equations and their written descriptions were as varied as the students.

But, what is critical in looking at this example is how the integration of mathematical relationships with the understanding of the growth of civilization can begin to develop a mathematical frame of reference – an orientation and a way of viewing the patterns, relationships, and symmetries of mathematics as a part of all human learning and experience.

### **Core Mathematics Program – Mathematical Investigations**

IMSA's core mathematics program is entitled Mathematical Investigations. It is an integrated four-semester course sequence, designed to place greater emphasis on multiple representations of ideas, reasoning, problem-solving, communicating and connections among mathematical ideas and among mathematics and other disciplines. Students study concepts from all areas of pre-calculus mathematics including algebra, geometry, trigonometry, data analysis and discrete mathematics and they do so in an integrated problem-centered and collaborative manner. Students learn to use mathematics in a variety of intra and interdisciplinary settings in addition to advanced studies in mathematics.

The goals of Mathematical Investigation are to:

- Integrate topics from all areas of pre-calculus mathematics.
- Enable students to discover connections between and among algebra, geometry and trigonometry concepts.
- Enable students to pursue calculus at the advanced placement level and to participate in other mathematics electives such as discrete mathematics, statistics, or courses in problem solving.
- Enable students to question their assumptions about the learning and practice of mathematics, explore ways of verifying things for themselves, and apply mathematical knowledge to different contexts.
- Enable students to be responsible for accessing their own knowledge base rather than relying on review by the teacher.

Courses use two simultaneous instructional strategies. The first one involves in-class investigations conducted in small collaborative work groups using computer and graphing calculators. The second one involves weekly problem sets. Students are given a series of

30-40 problems for which they have one week to complete them. Each problem set is designed to introduce multiple concepts and students are encouraged to work collaboratively on the solution of each problem. This integrative, explorative approach to Mathematical Investigations allows the Academy to incorporate multiple dimensions of mathematics, including data analysis and discrete mathematics. Mathematical Investigations is about “putting different things together, not matching algorithms...; the math becomes theirs...” (Ron Vavrinek, IMSA Mathematics Teacher, personal communication, 1999).

## **Core Science Program – Scientific Inquiries**

IMSA’s core science program currently being piloted, is entitled Scientific Inquiries (Torp, Dosch, Hinterlong, and Styer, 1999). It provides students with a rich and rigorous core science experience that explicitly infuses the power of student inquiry into the science curriculum.

The goals of Scientific Inquiries are to:

- Immerse students in rich science content.
- Engage students in the identification and resolution of problems which integrate the learning and doing of science.
- Inspire students to continue their interest in and study of science and technology throughout their lives.
- Support students in becoming integrated learners characterized by complex thinking.
- Challenge students to demonstrate their genuine understanding of concepts through the use of multiple forms of assessment (IMSA is now in the process of developing the framework for an Integrative Learning Portfolio that will represent the students coherent integration and synthesis of all dimensions of their thinking over three years).

Specific scientific inquiries (inquiry modules) have been designed to expose students to the unifying concepts and processes of science in a recursive way in order to enable them to progressively build awareness and knowledge and then to deepen that understanding for future learning in science.

The program is guided by the question posed from the student perspective: *How do I come to know the natural world and the universe around me, and my place in it?*

The learning experiences in this two semester sequence are initiated by phenomena or problems providing a compelling reason to learn, investigate, and collect evidence in support of a growing understanding of scientific concepts and processes as they relate to significant issues and topics of interest or essential processes. In this way, Scientific Inquiries consists of learning investigations that engage students in the purposeful pursuit and generation of knowledge. These investigations may be as simple as one that can be

solved during one instructional period (95 minutes) or as complex as one that will require several weeks or months of study.

As students delve deeper into their study, teachers take on facilitative, coaching, and mediating roles as well as modeling the investigative processes as co-learners with students. In this way, teachers function in multi-faceted roles as co-learner, investigative guide and resource. The Scientific Inquiries class is designed to be an authentic learning community, where the power of the idea to be understood is placed at the center of the inquiry. Both teacher and learner are engaged together in a communal and reciprocal process of discovery.

Essential to the philosophy of Scientific Inquiries is to engage students in learning science concepts and processes in a way that practicing scientists might encounter them, i.e. through enticing phenomena or compelling problems. With the creation of inquiry-based learning environments, it is expected that students will discover the need for particular conceptual understandings or skills to be mastered before progress can be made on the broader problem or phenomenon under investigation. In practice, carefully designed instruction will be offered to enable this understanding or skill to be learned or practiced within the context of the module or problem. Thus, the learning experience satisfies a desire to know when that desire is strongest.

We know that practicing scientists seek connections or explanations by progressively adding to what they already know in order to understand the system or issue deeply. Similarly in the Academy's program, students will be exposed to the unifying concepts and processes of science several times, as well as in multiple contexts, thus building and adapting a cognitive framework in an expanding web of connection.

Examining a concept repeatedly, from more than one perspective and in more than one context, develops the richness of encounters necessary to extend the concept's importance while honing one's deeper understanding of it. Applying knowledge to novel situations and weaving concepts and processes through contextual inquiry embodies the integrative and exploratory nature of science.

Scientific Inquiries will support students in their desire and need to become responsible for their own learning by encouraging and promoting student inquiry within the context of assessment of competencies through dialogue, observation, intentional coaching, and professional guidance. Teaching strategies that foster student ownership and inquiry-based learning are used. As a result, students who are self-confident and self-directive science learners will develop and thrive.

The excitement students experience when they are engaged in their own inquiry is illustrated in this sophomore student's thinking log.

### *I Love this Place!*

*This is the strangest place I've ever been. It is the only place I know where people can sit around at lunch and argue honestly about the velocity of a falling blob of ketchup. (Yes, that really happened)...I think that this is the only place where people can sit around and discuss physics and feel NORMAL while doing so.*

*...as soon as sophomores arrive here, IMSA begins to affect them. I know it is affecting me. People I know have observed me changing, and have told me about it.*

*[For] example: Last night my roommate was drinking soda from a glass cup, and for some reason all the foam stayed at the top so that while the liquid went down in the glass, the foam remained on top so that there were gasses in between.*

*(She included an illustration.)*

*She shouted, "Hey, look!" We all rushed over and stared at her soda for a few minutes. Then we tried to figure out why it did that. Finally, one of my roommates grabbed a camera and took a picture of it for our photography class. It was really an interesting occurrence.*

*I love this place!*

## **Problem-Based Learning**

We believe it is imperative that opportunities for authentic inquiry be created so that our students are immersed in an environment where they can learn and demonstrate skills for sensing and finding problems, for constructing arguments, for scaffolding complicated performances, and for developing the predispositions necessary to apply scientific understandings in the context of engaged learning and problem-solving.

One example of an interdisciplinary problem-centered course taught by a chemistry and social science instructor is called Science, Society and the Future. It utilizes an instructional pedagogical system called Problem-Based Learning (used in many medical schools in the United States).

Problem-based learning is an educational approach that organizes curriculum and instruction around carefully designed (by the teacher) so-called 'ill-structured' problems. In this course of study, students are confronted with ethical questions and the implications inherent in making public policy decisions about controversial scientific issues such as electro-magnetic fields, fetal tissue research and nuclear waste.

Armed with only minimal information on an issue or undefined and messy problem, students assume a stake in the problem (take a role within the problem) and investigate data, apply knowledge from multiple disciplines and determine whether or not a problem exists. Then, guided by teachers trained as cognitive coaches, they generate questions, conduct research, analyze data, formulate policy options, choose and defend their proposed solutions, anticipate implications and consequences for society and design controls accordingly. Problem-based learning is the essence of apprentice investigation.

This purposeful engagement with compelling questions enables students to embrace complexity, find relevance and joy in learning, and enhance their capacity for creative and real-world problem solving. They integrate and connect domains of knowledge that relate to their problem and they build substantial knowledge bases to increase self-directed study, which is structured around the topics of their inquiry. Confronting students with ill-defined problems, the kinds presented in the real world, is the essence of this course and the Academy's program.

Kathy Plinske (Marshall, Ramirez, Plinske and Veal, 1998), one of our graduates summarizes her IMSA experience in this way:

*At IMSA, we often were asked questions that motivated us to discover the necessary information for ourselves. We learned various methods and gained many different skills to help us gather accurate information...we used traditional sources of information and electronic resources including the Internet and World Wide Web. By senior year we had dealt with many real world issues including validity and relevancy of information, and we understood there was often more than one solution to a problem. We were able to handle almost any situation we were given – from determining what a data set of more than 3000 points told us, to collecting our own data through experimentation...my IMSA experience has helped me develop a type of 'fearlessness' with information.*

## **Student Inquiry and Research Program**

Student Inquiry and Research (SIR) serves as an essential component of the academic program. Students work independently and collaboratively with their peers, practicing scientists, and scholars. These experiences foster their development as highly skilled and integrative problem-finders, problem-solvers, and apprentice investigators, allowing them to develop the skills required to succeed in the world of the 21<sup>st</sup> Century.

### ***The Goals of Student Inquiry and Research at IMSA***

The Student Inquiry and Research program challenges students to engage in scholarly and scientific investigations, as well as artistic expression. In order to meet learning standards, generate knowledge, make connections, and develop a richer understanding of self, the world and their place in the world, students investigate questions and plan disciplined

creative work. This extends their use of knowledge, reason and imagination. This process culminates in the exhibition of products of ethical research and inquiry.

The goal of the SIR Program is to build the capacity of students to design and execute self-directed learning experiences that develop the habits of mind of an integrative learner. As a result, students become skeptical inquirers who work at increasingly higher levels of independence, guided by professionals knowledgeable in their fields. Participation in the SIR Program encourages active student questioning, investigations and presentation, situated in the context of concerns shared by a community of learners.

### ***Inquiry and Research Opportunities***

IMSA's SIR Program provides a variety of research and inquiry-based learning experiences for students to pursue compelling questions of interest, conduct original research in science and other fields, create and invent products and services, share their work through presentation and publication, and collaborate with other students and scholars throughout the world. Many students subsequently present their research in local, national and international research forums, state and national competitions (Intel Science Talent Search Competition, Siemens-Westinghouse Competition, Junior Science and Humanities Symposium, Sakharov's Readings) and refereed scholarly journals.

Students participate in the SIR Program through one or more of the following learning experiences:

Mentorship: In this interactive research partnership, students are paired with scientists and master scholars in museums, corporations, educational institutions and research laboratories in the Chicagoland area. Research is conducted on-site in a variety of disciplines, reflecting the student's passion for a particular subject and the mentor's expertise.

Inquiry: This is an in-depth study of topics reflecting students' interests, guided by an experienced IMSA staff or faculty member. Self-directed student plans of inquiry are a set of learning experiences that are created, designed, developed and demonstrated by students' questions. Students pose and answer a specific question or problem. The knowledge generated as a result helps students gain a deeper understanding of the topic.

IMSA Courses: In-class inquiry must meet the criteria and process requirements that are established for student Plans of Inquiry. In-class inquiry is an iterative process of investigation into a problem, problematic situation, model or phenomenon. Inquiry stirs questions born of limited information. This challenges the student to get inside the learning situation – to probe, question, and test ideas within the process of learning in the classroom.



## **Assessment of Learning**

To measure student achievement we look at what students are actually doing in and out of the classroom. We assess student presentations, experiments, research and inquiry projects so that both they and we can see demonstrated evidence of students' ability to think independently; conduct research; formulate problems; communicate; collect, analyze and synthesize data; and ethically solve complex problems.

We are now in the process of framing the design of a comprehensive system of assessment that will not only assess competence in our content and inquiry standards, but, more importantly, will assess growth over time on dimension of intellectual development, metacognition, and the habits of mind characteristic of integrative ways of knowing described in our Standards of Significant Learning.

### ***Traditional Indicators***

IMSA students historically perform at the upper 2-3% of the U.S. student population on traditional norm-referenced exams (Scholastic Achievement Test and the American College Test). In addition, their scores on the AHSME (American High School Mathematics Exam, an exam designed to identify and recognize talented mathematics students and potential mathematics Olympiad students) have ranked IMSA as one of the top five high schools in the nation. Furthermore, IMSA's own internal longitudinal study of AHSME scores indicates a small but statistically highly significant increase in scores after the introduction of IMSA's Mathematical Investigations program.

### ***Non-Traditional Indicators***

Concept Maps: Another strategy to assess conceptual understanding is the use of concept maps – a facilitative graphical teaching and learning tool that enables students and teachers to recognize both students' understanding and gaps in understanding. IMSA uses concept mapping largely in science as a pre- and post-assessment to diagnose scientific misconceptions and to demonstrate growth (or lack of growth) in conceptual understanding. This visual representation of cognitive structuring graphically demonstrates the learners' understanding of facts, concepts, propositions and principles.

Thinking Log: A strategy developed for assessing our students' ability to discover and forge connections, is an instructional tool called 'The Thinking Log' – a cognitive diary of ideas, concepts and questions where students record their thinking about their own thinking. Here is an example of a thinking log prepared by a first semester sophomore student (age 15):

*In school today, in English class, second hour, I thought of something. Socrates and special relativity have a lot in common. For Socrates, different perceptions may produce different truths or realities. In special relativity, the velocity of an object is relative to the observer—it changes.*

*For Socrates, there is no true reality. In special relativity, there is no real velocity.*

*For Socrates, God's reality is the only real one, but we can never really know it. In special relativity, the speed of light is the ultimate reality, but we can never really reach it.*

*For Socrates, each point of view, each reality is valid if it can withstand interrogation. For special relativity, each different velocity is valid if it is congruent with the equation for velocity (and she included the equation in her notebook).*

*I don't know if the way I worded these comparisons makes a whole lot of sense, but it was perfectly clear to me in English [class] today.*

*In addition, Socrates says not to give blind respect and judgment to people and things. The unexamined life is not worth living, he said. So, if you don't understand and examine questions, it's pointless.*

*What good are they if you don't know where they came from, or why they work.*

Although the Academy's Resident Nobel Laureate gave this first semester physics student a C in physics understanding, this entry illustrates the potential power of consciously practicing trying to think in more integrative ways, using the concepts in one discipline to elucidate the concepts in another discipline and employing, where appropriate, multiple representational symbol systems to unlock concepts. At the very least one can say that thinking about special relativity in English class is atypical!

IMSA's work now is to design assessments that provide evidence of the growth of the 'new mind' we are seeking to invite. Such assessments must be challenging, contextualized within authentic, real-world problems, and generative.

## **Two Stories**

Why did IMSA choose this direction?

The structure of schools as we currently know them must be transformed because their curriculum and instructional and assessment structures are antithetical to the principles of human learning. Schools are therefore not able to develop the integrative and collaborative mind. There is a powerful, often unconscious, paradigm of teaching and learning that is currently manifest in most schools. It is grounded in erroneous understandings about learning and the principles necessary to create learner-centered environments that genuinely liberate the learners' talents. I have characterized these assumptions as

grounding the ‘current story of schooling.’ That story is based on a culture of acquisition, individualism, and competition.

### ***The Current Story of Schooling***

The following assumptions underlie the current story of schooling:

- 1) Learning is grounded in an epistemology that honors the objectively verifiable, the analytical and the experimental; that views empirical observation as the most important skill; that believes that the acquisition of factual knowledge requires the disengagement of the learners’ emotions in pursuit of objective truth; that believes that subjectivity endangers the pursuit of objective truth and that holds to the premise that there is no relationship between the knower and the known.
- 2) Learning is an externally directed, passive and linear process of acquiring information; false proxies (seat time, courses taken) are legitimate indicators of learning.
- 3) Intelligence is a defined and fixed capacity and is not learnable; analytical intelligence is the highest form of intelligence.
- 4) Learning should be credentialed by the amount of time spent acquiring information; emphasizing authentic learning tasks that are complex, challenging and novel, interferes with content and information acquisition.
- 5) The purpose of schooling is to rapidly acquire information, cover content and reproduce facts.
- 6) Prior knowledge is unimportant and a detractor to future learning.
- 7) Content segmentation, not concept integration, is the more efficient and effective way to learn a discipline.
- 8) Rigorous and reliable evaluation of learning can only be objective and external; only that which can be quantitatively and easily measured is important knowledge; content coverage and information reproduction, not knowledge generation, are the most reliable indicators of learning.
- 9) Competition and external rewards are the most powerful motivators for learning.
- 10) Schooling represents a necessary rite of passage; what happens in school prepares one for life.
- 11) Personal inquiry and the exploration of the learners’ questions are not significant enough to take time away from the prescribed curriculum.
- 12) Emotions, beliefs and personal realities constructed from prior experiences do not influence and are not relevant to serious learning; they are only permitted if they do not significantly derail the curricular objective.

What all these assumptions point to is the view of a passive and disengaged learner and a one-size-fits-all system that stifles our natural desire to learn. What we have come to understand at IMSA is that empowering and meaningful learning environments are created by intention and by design. We are fortunate that new insights from the neuro- and cognitive sciences can now help us to create the conditions that invite human learning naturally in more effective ways than ever before. Sadly, however, despite these new

understandings and new knowledge, most schools continue to be structured as if the mind functions best in a prescribed predictable and ‘sanitized’ environment. It is our belief, therefore, that as a result far more children are ‘school disabled’ than they are ‘learning disabled’.

### ***The New Generative Story of Learning***

What does this all mean for IMSA?

It means that we are constantly trying to create conditions that foster the use and transfer of multiple symbol systems for learning; that connect mathematics and science with the arts and humanities; that require the consideration of ethical issues in the resolution of scientific problems; that foster interconnection and integration with real world issues; that immerse students in inquiry and messy ill-structured problems; that require collaboration; that inspire passion and curiosity and that give students the opportunity to liberate their goodness and genius for the world. (IMSA Vision – Appendix A). I have characterized this commitment as the ‘New Generative Story of Learning’ and have enumerated its grounding assumptions, which are based on a culture of inquiry, interdependence and collaboration.

These assumptions are:

- 1) Learning is grounded in an epistemology that affirms integrative ways of knowing; that believes meaning and connections are constructed by the learner; that affirms the power of relationships and community in learning; that believes the learners passion and love are essential for deep learning; that understands that relatedness and engagement are at the heart of learning and that there is a profound connection between the knower and the known.
- 2) Learning is a self-directed, internally mediated dynamic process of constructing meaning through pattern formation.
- 3) Intelligence is learnable and potential and capacity for learning are inexhaustible and expanding.
- 4) Learning is credentialed by demonstrations of understanding, anytime.
- 5) The purpose of education is to develop understanding, wisdom and the tools for lifelong learning through the reflective and often slow exploration of essential questions and through engagement in meaningful and challenging work.
- 6) Prior learning is essential to future learning.
- 7) Concept integration is the most meaningful way to understand the unity of knowledge.
- 8) Rigorous and meaningful evaluation of learning must include qualitative evidence of understanding, be self-correcting and be demonstrated in settings that are real-world.
- 9) Collaboration, interdependence, and internal rewards are powerful motivators for learning.
- 10) Learning is a continuous lifelong engagement; what happens in school is life.

- 11) Personal inquiry and the exploration of deeply human questions are the means through which children acquire the knowledge and skills they need to construct meaning.
- 12) The total engagement of the learner (intellectual and emotional) is essential for the construction of meaning.
- 13) Engaged learning requires an intergenerational community learning together.

Every epistemology gives rise to a pedagogy; how we teach is derived from how we believe people come to know. Enacting the new story of learning thus creates generative learning communities that invite students to become actively engaged in the development of their own mind.

Recently one of our graduates returned to the Academy from college and I asked her, “How did IMSA prepare you for college?” Her answer was disturbing. “IMSA did not prepare me for college,” she said. “IMSA prepared me for graduate school. In college you are taught to memorize, memorize, memorize. I am waiting to get to graduate school so that I can think again.”

### **Imsa’s Continuing Journey**

Within the context of this new story of learning, there are a number of issues with which we are currently wrestling and our hope is that our wrestling with them in the public arena, with an open invitation to our colleagues to engage with us, will not only open up the discourse but will inform the work we are all engaged in on behalf of the learning of our children.

Some of these issues and questions are:

- 1) Are there necessary tradeoffs between the amount of content a student acquires and the degree and level of his/her conceptual understanding?
- 2) If a student excels on a standardized test, should the public assume conceptual understanding?
- 3) How much content is essential for conceptual understanding and integrative thinking?
- 4) Does interdisciplinary and integrative learning diminish or reduce a student’s ability to acquire disciplinary understanding and disciplinary modes of inquiry?

As a laboratory and a practical field for designing and testing new strategies for teaching and learning, the Illinois Mathematics and Science Academy is a work in progress. The work that lies ahead is perhaps best captured in the question posed by a 15 year old female student in her thinking log.

*I wish I could still draw. When I was in grammar school I used to draw pretty decently. I love to draw in pencil and chalk. Art of all kinds intrigues me, but I*

*also love music and painting, and carpentry and metal working, and dancing, and sewing and embroidery, and cooking.*

*I want to dance in my old ballet class, play my clarinet, draw thousands of pictures, really good ones, create beautiful poems and pieces of woodwork, cook and sew for my children, decorate my home, have a good marriage, be an active volunteer, go to church, be an astrophysicist, go to Mars, and understand all my questions about life.*

*That's not too much to ask, is it?*

So often, we give children cues that their dreams are far too big. So we tell them to be 'realistic,' as if reality was an established condition. IMSA is striving to provide a learning environment where students have developed the knowledge, tools, ethics and confidence to ask and explore 'what is possible now.'

### **Personal Reflection:** **Transforming Public Schooling into Community Learning**

It is my belief that as educators, we are at a critical junction with respect to our willingness to fundamentally reinvent public education. Past efforts that have focused on reform or restructuring have only made the old paradigm more efficient. Somewhere there has been a profound disconnect between school age education and life-long learning. Public education cannot serve the needs of future generations, unless the kind of mind we nurture develops our capacity to become more fully human and sees as its work, the creation of a compassionate and sustainable world that works for everyone.

Devoid of a compassionate and sustaining human context, public education cannot serve the public good. As a consequence, I believe we must transform the current paradigm of schooling, which created structures that stifled children's needs for meaning and sense-making; for reflection and complex cognition; for exploration and discovery; for risk, adventure and surprise; and for integration and connection with the natural world, into a vision of education that creates whole, healthy and vibrant learning communities that liberate the goodness and genius of all children for the world. It is, therefore, our work, to create a generative paradigm of learning that invites not only the fullness of our intellect, but the fullness of our imagination and the fullness of our spirit.

This vision is premised on several beliefs, enumerated below:

- Human beings inherently possess goodness and genius.
- Liberating the goodness and genius of children is essential to our sustainability.
- The fundamental purpose of education is not to credential vocational knowledge and skills, but to build the capacity of each learner to advance the human condition.

The current structures of schooling, grounded in false and disabling assumptions of human learning, are not capable of re-igniting the power, courage and imagination of children for the world. They are not big enough to enable children to respond to their real questions about life and they are not spiritual enough to enable children to see how they belong to the world and to one another.

In order to create a compassionate and sustainable world, a new global consciousness must become manifest and this can only come from a paradigm of generative, not prescriptive learning; it is this paradigm that grounds the design of a new story of teaching and learning. The attributes of the current culture of schooling – rapid information acquisition, disintegration of knowledge, individualism and competition – reflect our societal ambitions and predispositions. Schools, in fact, have executed the current cultural norms, values, priorities and reward structures (of most developed nations) quite well.

This ‘success’ has been at an enormous human and environmental cost, however, and the result has been the emergence of a global mind focused on capitalism, consumption, competition, acquisition and winning. The deep systemic problems that are now casting a malignant shadow over the global community, and our own society and institutions, will not be resolved until we recognize and re-connect to what we have lost.

- The acquisition of wisdom and the power of discernment.
- Compassionate use of knowledge.
- Integrative ways of knowing and sensing.
- Concern for human and community prosperity and moral action in the world.
- Commitment to ecological sustainability and the acceptance of nature as a sacred dimension of our lives.
- Willingness to engage slowly, around issues of long-term consequence.
- Deep awareness of and appreciation for our intimate relationship with and integration in the profoundly interconnected living world.
- The understanding that real learning comes slowly, through the construction of meaning, the recognition of patterns and the creation of relationships.

These attributes of a generative learning paradigm create a framework for a new epistemology, a new pedagogy and a new learning community – all of which offer the possibility to invite the creation of a new global mind – a mind capable of creating a compassionate and sustainable world that works for everyone.

At this juncture in time, we confront two life-defining challenges:

- 1) How to solve the deeply human problems facing us as a global civilization, problems for which our current system of education does not provide congruent context, vibrancy, practice or affirmation?
- 2) How to create learning conditions that liberate the goodness and genius of all children for the world?

The promise of this time in human evolution, is that by unleashing the unprecedented capacity and power of the human mind for the world, we set in motion the possibility of inventing a world that works for everyone

All of our students are desperate to thrive. If we want our students to demonstrate understanding at higher levels of complexity and deep understanding of concepts and constructs; if we want them to engage in meaningful work, genuine research and serious inquiry; if we want to enhance their opportunities for collaboration and exploration; if we want to give them opportunities to authentically study problems of significance in a learning environment that promotes mathematical investigations and scientific inquiry (and the integration of the arts and humanities) and if we want to create a learning environment that honors who they are and how they learn, we must focus on creating the conditions that we know will more likely increase the learning capacity and power of each student.

If we don't, I fear we will continue to develop youngsters who do not have the tools to understand the complexities and interconnections among different forms of knowledge and ways of knowing, who are afraid to risk or experiment because it isn't on the examination, who seek simplistic, narrow and expedient solutions to complex problems, and who have not developed the intellectual fluency and repertoire to become lifelong learners.

As a result, I struggle now with the need for new language to describe and new tools to measure the efficacy of the learning conditions that must be designed and implemented in order to invite our children to create new minds, minds that can imagine and feel compelled to create, a sustainable world that works for everyone.

Educators must think about the learning environments we create as analogue to a learning biosphere, an ecosystem intentionally designed to grow and nurture specific habits of mind. Most challenging in that context is the realization that growth in a living system is not quickly observable or easily quantified and that what is easily observable or quantified may not represent sustainable growth or health.

How to authentically assess the learning of integrative ways of knowing, ethical leadership, moral reasoning, problem formulation, knowledge generation and knowledge application in novel situations, for all learners, is one of the essential issues we must resolve.

Until we do so, I believe that children will continue in their state of educational somnambulism – they will be sleepwalking their way through their education, because the structures of the current system, by design mitigate against deep and reflective study, the passionate exploration of ideas, thoughtful analysis of questions and issues, genuine collaboration and serious inquiry and research and in so doing deny them genuine access to participate fully in and grapple with issues of human significance. As a result, they will emerge from this system of learning with minds, hearts and spirits unable to deeply



comprehend and make sense of the complexity and interrelatedness of the problem facing the human family.

Children are bored in places called schools, not because we ask them to do too much, but because we engage them in work that is far too small for their imagination. IMSA is seeking committed partners to work with us in creating profoundly more meaningful and spiritfuf ways to develop and assess deep human knowing so that all students have the habits of mind required to embrace with eagerness and confidence, whatever lies ahead – as pioneers in an unknown land.

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## The Illinois Mathematics and Science Academy

### *A Pioneering Educational Community*

#### IMSA PHILOSOPHY STATEMENT

"If we do what we know and feel is right, it is bound to happen that among our graduates there will be numbered scientists, engineers, and those who go on to earn degrees in law and letters. There are likely to be those few who create new intellectual worlds, cure a dreaded human ailment or in some other way **significantly** influence life on our planet. Our philosophy will be to treat our charges as if each one is capable of this extraordinary achievement...".

**IMSA Philosophy Statement**  
**Board of Trustees**  
**April 1985**  
**(authored by Leon Lederman)**

#### IMSA'S VISION

**To create a learning enterprise** that liberates the genius and goodness of all children and invites and inspires the power and creativity of the human spirit **for the world**.

#### IMSA MISSION

**To transform mathematics and science teaching and learning** by developing ethical leaders who know the joy of discovering and forging connections within and among mathematics, science, the arts, and the humanities by means of an exemplary laboratory environment characterized by research, innovative teaching, and service.

#### IMSA GOALS

By the year 2003, IMSA will be a recognized exemplar and a national leader in mathematics and science teaching and learning.

By the year 2006, IMSA will be a recognized pioneer and architect in the design of a new system of learning that is inquiry-based, problem-centered and integrative and that enables learners to acquire, generate and use knowledge for the world.

#### IMSA'S CORE COMPETENCY

Ability to conceive, design, develop and demonstrate exemplary, competency-driven teaching and learning experiences and materials in mathematics and science that are inquiry-based, problem-centered and integrative.

#### IMSA OBJECTIVES

There will be a generally accepted paradigm for teaching and learning mathematics and science that embodies interconnections as the basis for understanding.

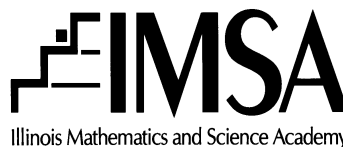
The achievement of Illinois students in mathematics and science will be defined and assessed by a new system of indicators.

Materials and methods inspired or developed by IMSA and its partners will be so good that they will be the choice of Illinois educators for the foundation of their mathematics and science programs.

**Illinois Mathematics and Science Academy**  
*A Pioneering Educational Community*

**BELIEFS:**

- meaning is constructed not prescribed.
- all individuals have equal intrinsic worth.
- all people have an innate desire to learn.
- the human mind is the world's greatest resource.
- each person has the potential to change and to bring about change.
- without trust no human relationship can thrive.
- the survival of global civilization depends primarily upon the quality of the education provided to all people.
- each person is responsible for his/her own choices and actions.
- belonging to a group requires alignment of self-interests and the common good.
- excellence is worth the effort, but not always worth the costs.
- aversion to risk-taking stifles innovation and creativity.
- learning is an individual, life-long endeavor.
- valuable learning results from both failing and succeeding.
- all adults share responsibility for the well-being of all children.
- the ability to discern and create connections is the essence of knowing.
- a good life is characterized by harmony among the emotions, the body, the intellect, and the spirit.
- the process of education is more than the accumulation of facts.
- ethical conduct is essential to a harmonious life.



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