

Integration of Technology, Science, and Mathematics in the Middle Grades: A Teacher Preparation Program

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How middle grade teachers in science and mathematics are prepared should be consistent with the vision of what and how students should learn mathematics and science, in particular the integration of these two fields. In this article a teacher preparation program for middle school mathematics and science teachers that emphasizes the integration of math and science with each other and with technology is outlined. First a theoretical framework for the integration of technology is described. Then some examples of uses of technology, such as the use of the Internet, and of interactive and dynamical software that lends itself to establish connections between mathematics and science are given.

The national standards for mathematics (National Council of Teacher of Mathematics, 2000, 1991) and for science (National Research Council, 1996; American Association for the Advancement of Science, 1993) emphasized that educators should prepare students to be literate in mathematics and science, as well as in technology. Yet there is evidence that most middle school classrooms do not use technology appropriately in the teaching and learning process (Jensen & Williams, 1992). One of the goals of the teacher preparation program described in this article is intended to rectify this situation.

TEACHER EDUCATION FOR ARIZONA MATHEMATICS AND SCIENCE (TEAMS)

The mission of TEAMS is to prepare middle school mathematics and science teachers by modeling the use of tools, technologies, and strategies that are consistent with national mathematics and science standards. The

standards are the framework for the program and teaching, and also for the teaching, curriculum development, and assessment that prospective teachers are expected to carry out in their own classrooms.

This program supports the reform in middle grades mathematics and science by providing a model for preparing teachers in a way that is consistent with the middle school concept. According to this view, the primary focus of middle school is to meet the needs of young adolescents. It is a bridge between the elementary and high school. It is student-centered rather than content centered. Teachers meet the needs of students by incorporating (among other things) flexible block scheduling, interdisciplinary thematic curriculum units, teaming in planning and teaching, and cooperative heterogeneous grouping. An important assumption of this program is that mathematics, science, and technology should be integrated, but both mathematics and science must retain their integrity.

Students in TEAMS are post-baccalaureate individuals who possess degrees in science, engineering, mathematics, or technology. The TEAMS program is one calendar year and leads to students receiving science or mathematics certification for grades 7-12, a middle school endorsement for grades 5-8, and a master's degree in secondary education.

During the year faculty and students engage in a variety of real-world mathematics, science, and engineering experiences: field trips to various sites within the state; internships in informal education settings such as museums and botanical gardens; and visits to campus research centers. One goal is that prospective teachers observe and use technology while doing science and mathematics in these real-world settings so they can later authentically integrate these types of experiences in their future curricula as middle school teachers. Several kinds of technological tools are used during the year: (a) computers, (b) data probes and sensors, (c) multimedia and communication technologies, and (d) graphing calculators.

Fundamental to the process of students becoming teachers in TEAMS is an emphasis on early teenagers' learning with frequent opportunities to work with students in formal and informal settings. Prospective teachers observe and participate in middle school classrooms.

THE USE OF TECHNOLOGY IN LEARNING MATHEMATICS AND SCIENCE

To attain the vision of science and mathematics learning outlined in the *Standards*, *how* content is taught is as important as the content itself. In the same way, *how* the technology is used is crucial if it is really going to help

middle school students in their cognitive growth and understanding of mathematical and scientific concepts. According to Pea (1987), cognitive technologies serve two transcendent functions. First, technologies have *purpose* functions. They serve to engage students in the activity of mathematical and scientific inquiry. This provides meaning for engagement, ownership of the mathematics and science being learned, and empowerment through the generation of personal agency. Technologies engage students in more powerful scientific and mathematical activity in a way that could not be approached without them. But technologies are not by nature engaging. To achieve this quality, they must be both functional (teachers and students must be able to do with them something that they could not do without them), and they must increase communication and facilitate collaboration.

Second, technologies have *process* functions. Some of the tools available for students should free up their working memory so that they are able to concentrate on problem formulation and modeling. If a middle school student is bogged down with computing or graphing, the big picture of number systems, functions, families of curves, etc., is lost. Other tools must provide opportunities for exploration and discovery. In a mediated learning environment, some agent (teacher, peer, tool) must bridge the informal knowledge of the student and the formalism of mathematical and scientific structure. Still other tools must provide ways of representing mathematical and scientific models and linking representations to make the underlying commonalities transparent (Lesh, 1979). A single technology rarely has all these process functions. However, a careful selection of tools and software as described in this article can help achieve the necessary complementarity.

Two other features of cognitive technologies are necessary for the development of coherent mathematical and scientific structures. The first is what Roschelle (1996) called *epistemic fidelity*. This refers to the requirement that any teaching tool must reflect and develop understandings that are true to the field of study. Students' mathematical and scientific activity should develop the kinds of understandings that experts in the field would recognize. Two caveats are in order. The road from novice to expert goes through several transformational periods and may not be immediately recognizable as important without an understanding of students' cognitive development. Second, the sophisticated knowledge of the expert cannot be handed to students. The path taken is as much a part of expert understanding as the final product.

The other necessary feature of cognitive technologies should focus the students' attention on the mathematical structure of the experiences and provide them with a means of communicating their thinking about this

structure to others. This is, in its basic form, the engagement of students in mathematical and scientific modeling.

The vision that guides the integration of technology, science, and mathematics is the engagement of students in activity that elicits the development of mathematical and scientific models with a coherent epistemological framework. The movement from informal discovery to more formal models marks an authentic transition between the exploratory knowledge of the student, and the theoretical knowledge of the expert (Kozulin & Presseisen, 1995).

Six principles guided the design, choice of equipment, and software (Middleton & Goepfert, 1996).

1. *Technologies are only tools.* Technologies neither supplant the thought processes of students, nor do they make learning fun or easy. Technologies are instruments that should be used judiciously at the proper time in the proper place.
2. *Technologies should enable students do what they could not do without them.* When used appropriately, technologies help students expand their zone of proximal development. This can serve to make learning more intentional, powerful, and connected. In addition, computer technologies can represent situations unfeasible with other types of tools.
3. *Technologies must be on hand all the time.* The context, social setting, and tools that students use to construct their mathematical and scientific knowledge are inseparable from the knowledge itself. For technologies to be authentically integrated into students' learning activity, they must be available when the question arises.
4. *Tools should facilitate the creation of sharable, modifiable, transportable models of mathematical and scientific concepts* (Lesh & Doerr, 2000). Technologies facilitate the development of public records of thought. These records should be shared as students develop, refine, and test models of mathematical and scientific phenomena. It is crucial that students can modify them, as most models students construct in the beginning are either incomplete, or contain misconceptions. Through discourse, the shared model can be pared down into a workable model that can serve the class as a whole.
5. *Sharing of data/resources should be simple.* Technological systems should be user friendly. The mechanism of communication should not be more complex than the learning process itself.
6. *The setup of the workstations should facilitate collaboration between*

students. As collaborative tools, technologies are imbedded within the geography, culture, and psychology of the classroom. The setup should facilitate collaborative inquiry, but also engage students in independent exploration.

As can be inferred from these principles, the kind of software and the way it is used are also crucial elements. Common features of the software used in this program are that it can be used by middle grade students; it is user friendly; it is designed for the kind of computers available in schools; and most important, students are in control, telling the computer what to do rather than the computer telling students what to do. The kinds of software used range from general purpose tools to specialized programs for science and mathematics learning. The particular software used can change from year to year. Typically, four or five kinds of technology are used in depth, including computer-based software and graphing calculators. Although prospective teachers become quite expert in the use of the technology, the main goal is that their future *students* use technology to explore concepts and solve problems in science and mathematics. In addition to the examples given in this article, the reader may want to see the examples given by Garofalo, Drier, Harper, Timmerman, and Shockey (2000).

An important emphasis of the integrated approach in TEAMS is that technology is not the only tool to be used. Prospective teachers use it in conjunction with hands-on materials, such as geoboards and polyhedra, and activities such as paper folding. Use of natural objects and outdoor activities are also an important part of integration

TEAMS AND THE INTERNET

The use of Internet resources is an integral part of the use of technology for prospective middle school teachers. The first tool developed was a web site meant to provide faculty members with a dependable vehicle showcasing their work in TEAMS and other aspects of their professional life. Its function is also to provide access to potential participants and interested colleagues. It serves both for dissemination and recruiting of new candidates for the program.

The program also provides experiences for the participants to learn design and management skills using the web. This aspect of the TEAMS project also serves a double purpose. On one hand, it is a means of disseminating information about our courses and activities. Another function is to let participants learn by actually developing homepages and instructional

units, using multimedia applications and authoring tools. The Internet also serves as a tool to facilitate the communication of faculty, mentor teachers, and students in the course of student teaching.

Of course, there are other Internet uses important for middle grades teachers that would be impossible to describe with detail in this article. These include content understanding activities, such as archives, news sources, databases, connections to others, resources for teaching such as video, software, and communications, and electronic portfolio development such as project reports, videos of classrooms, thematic units, internships, and interactive multimedia.

One tool that has been valuable is electronic mail. Students exchange ideas and experiences with their peers and with faculty, both individually and through a listserv. E-mail has provided a forum for them to vent concerns, share experiences, and express feelings and hopes. It also provides a record of teacher growth (Piburn & Middleton, 1998). The interchange of ideas and experiences through the server is especially important during student teaching, due to the fact that students are placed in different schools and could not interact face to face.

EXAMPLES OF OTHER TECHNOLOGIES USED

Interactive mathematics computer programs such as the *Geometer's Sketchpad* (Jackiw, 1995) and *RoboLab* (Lego Group, Tufts University, and National Instruments Corporation, 1998) can be used in the middle grades to establish connections between mathematics and science. At the same time, students get acquainted with important aspects of technology. Prospective teachers learn to use tools, doing the same kind of exploratory activities in which their own students in the middle grades could be engaged.

Guided Discovery With *Geometer's Sketchpad*

An important aspect of mathematical discovery is to learn how to conjecture and provide convincing evidence. This inductive approach to mathematics should be emphasized in the middle grades. A dynamic geometry program such as the *Geometer's Sketchpad* provides an environment in which prospective teachers can do the same kind of explorations as their own students will do in the future. One example given to TEAMS students is to join the midpoints of consecutive sides of an arbitrary quadrilateral. As

teachers change the original quadrilateral they will observe that the inscribed shape looks always like a parallelogram (Flores, 2001). They can state their conjecture and then provide evidence to convince others about their results. They can measure angles and opposite sides to verify that, in fact, the inscribed figure shares the same properties as a parallelogram. Teachers can then discuss the analogous process in science of enunciating hypotheses and then gather evidence to confirm or disprove them.

Feedback Systems

An idea central to modern cybernetics and many other fields is that of feedback. *RoboLab* has two kinds of devices: output devices, such as motors, lights, and sound, and input devices, such as touch sensor, light sensor, and angle sensor. These devices can be controlled with the computer writing procedures in the form of control charts. Prospective teachers use *RoboLab* to design artifacts with both kinds of devices and write programs that use a feedback loop to control them. Such programs engage students in the fundamentals of robotics, remote sensing, and control.

CONCLUSION

Science and mathematics educators cannot separate the vision of how we should prepare middle grade teachers in science and mathematics from the vision of what and how students should learn science and mathematics in the middle grades. Prospective teachers should have the same kind of experiences integrating science, mathematics, and technology as their future students. One of the goals of the middle school concept is the integration of science and mathematics with other areas. Teachers should experience how technology can be integrated in an authentic way, so that the integrity of both the science and the mathematics is preserved. Different middle schools incorporate to different degrees the ideal of the middle school concept. Prospective teachers can also take part of the approach presented here to implement change and support the necessary reform in mathematics and science teaching over time, regardless of the degree of implementation of the middle school concept in their placement school.

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