

Materials Science and Technology: What do the Students Say?

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Introduction

Materials Science and Technology (MST) is a multidisciplinary course developed to replace much of the dreary, tedious atmosphere of many traditional science classrooms with a stimulating environment conducive to learning. The course uses problem solving as the foundation of its approach to studying science and technology. Students learn problem-solving skills as scientists and technologists do through hands-on experimenting, creating, designing, and building. What are student perceptions of this course? This qualitative study examines the perspectives of students in three Materials Science and Technology classes at Desert High, a fictitious name for a large public high school in central Washington State. Like many high schools, Desert High is concerned with curriculum, student interest, parent expectations, and other problems that high schools face daily. The local community supports a university extension campus, many industries related to science, technology, scientific research, and agriculture.

The Status of Science, Mathematics, and Technology Education

As we frequently read, science, mathematics, and technology education are in trouble. The number of students taking these courses beyond the minimum required by state statutes is declining yearly. The National Center for Improving Science Education (NCISE) reports that “at least two-thirds of the nation’s high school students typically do not elect science courses or achieve well in those courses they are required to complete” (NCISE 1991, p. 1). NCISE also says that these students are disproportionately women and minorities.

In Washington State alone, Nelson and Hays (1992) report that even in the context of the state’s modest expectations in mathematics, science, and technology, students are not succeeding. They say that “although there are pockets of excellence, most science, mathematics, and technology education programs fall short of producing citizens prepared for the 21st Century” (p. 29).

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In light of these findings, Tobias (1991), Roy (1992), Krieger (1992), Hays (1992), and Nelson and Hays (1992) have reemphasized the need for reform in mathematics, science, and technology education. We have a science and technology illiterate society. Americans do not understand enough science or technology to make the political decisions required of them (Haggin 1992).

What is the problem?

Johns Hopkins University biology professor James D. Ebert summarizes well a myriad of descriptions offered by many experts in the field of science:

In today's schools, science instruction during the elementary school years is infrequent and inconsistent. During the middle school years, a student's window to the natural world is typically a textbook accompanied by dreary worksheets. As a result, students enter high school thoroughly bored by science and give no thought to the subject beyond the required courses, which more often than not affirm their expectations of an unrewarding experience (in Krieger 1992, p. 27).

Methods of instruction appear and reappear as the single most important factor cited in research as the cause of student boredom. Courses generally do not provide hands-on opportunities for students to experience live science. Rather, "the high school curriculum is characterized by strict disciplinary approaches that are limited to the body of knowledge with little attention to how that body of knowledge develops or how it makes an impact on culture and society" (NCISE, 1991, p. 1).

According to Tobias (1991), "what makes science hard may not be the science itself or the unpreparedness or prior alienation of high school and college-level students, but rather how science is packaged and purveyed--something we can all do a great deal to change" (p. 379). If this assumption is correct, a valid conclusion would be that the problem is not studying science, mathematics, or technology, but how these disciplines are being taught.

Therefore, a new curriculum using the active, hands-on learning strategies described below may help alleviate the problem and improve science, mathematics, and technology education:

- manipulation of equipment and materials (Tobin 1990)
- hands-on work to make connections to real life (Leonard, Cavana and Lowery, 1981; Johnson and Johnson, 1985; Tobin, 1986; Farrell, 1991; and Loudon 1991)
- real life connections and student involvement in decision making (Cothorn and Collins, 1992; Tobin, 1990; Carey, 1986; Hogarth and Einhorn, 1992; Archenhold, Cooke, and Sang, 1987; Farrell, 1991; Johnson and Johnson, 1985; Leonard, Cavana, and Lowery, 1981)

- incremental exposure to new material (Hogarth and Einhorn, 1992)
- use of writing to help students develop understanding (Cothen and Collins, 1992; Kalonji, 1992; Loudon, 1991; Fennell, 1991)
- cooperative learning for exchange of ideas and peer teaching (Farivar, 1992; Blosser, 1993; Starr, 1991).

The MST Course

The MST course offered at Desert High, and at more than a dozen other sites around the country, was designed based on some of the strategies described above. The course uses materials--broadly defined as the "stuff" that makes modern life possible--to bridge school science and technology and "real life."

The course was developed by Northwest teachers and staff of Pacific Northwest Laboratory (PNL), which is operated by Battelle Memorial Institute for the U.S. Department of Energy. The philosophy/rationale of the course is described as follows:

The philosophy that underlies this introductory Materials Science and Technology (MST) curriculum has as much to do with how things are taught as with what is taught. The instructional approach is based on the idea that students cannot learn through talk or textbooks alone. To understand materials, they must experiment with them, work with their hands to discover their nature and properties, and apply the scientific concepts they learn by 'doing' to designing and creating products of their own choosing...Students get a chance to use and build their mechanical skills as well as mind skills. We call this approach hands-on/minds-on learning...Students ponder, plan, experiment, goof up, correct, discover, and learn in a laboratory setting. (Pacific Northwest Laboratory 1993, pp. 17-19)

The course focuses on four major units of study--metals, ceramics/glass, polymers, and composites. Table 1 briefly outlines one example of the content of the course related to these units. Table 2 provides student learning objectives related to the example content.

Using a multi-instructional approach that includes elements to appeal to many learning styles, the course is designed to be taught to a wide range of students. Each unit typically focuses on (1) student experiments, individually and in groups, and (2) student projects, where students design, research, create and build individual or group projects. Designing and creating projects is often what draws students to enroll in the MST course, partly because they are attracted to the idea of building and studying something that is current and relevant to them.

Table 1

Outline of Course Content

- I. Introduction
 - A. Materials - The basic nature and properties of materials
 - B. Solid State - Materials divided into two categories: crystalline and amorphous

 - II. Body of Course
 - A. The Nature of Metals - Properties and characteristics of metals
 - B. The Nature of Ceramics - Properties and characteristics of ceramics
 - C. The Nature of Glasses - Properties and characteristics of glass
 - D. The Nature of Polymers - Properties and characteristics of polymers
 - E. The Nature of Composites - Properties and characteristics of composites

 - III. Topics to be Integrated
 - A. Physical Properties
 - 1. Thermal properties of materials
 - 2. Electrical properties of materials
 - 3. Strength of materials
 - 4. Optical properties of materials
 - B. Chemical Properties
 - C. Periodic Table of the Elements
 - D. Methods of scientific inquiry
 - E. Significant developments in the history of materials
 - F. Application of Materials
 - G. Systems of technology development
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Beyond MST's basic problem-solving approach through experimenting and creating projects, other fundamental elements of the course include fostering student creativity, developing handiness and journal writing skills, working in teams, and using community resources.

Table 2

Student Learning Objectives (overview)

On completing the course, the student will be able to:

- 1. Identify materials specific to our environment
- 2. Classify materials as metallic or non-metallic
- 3. Classify materials as crystalline or amorphous

Table 2 (continued)

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4. Understand the basic properties of materials: mechanical, thermal, chemical, optical, and magnetic
 5. Understand that the properties of a material are governed by chemical bonding and crystal structure
 6. Understand that the properties of materials can be altered by changing their chemical makeup or physical makeup by treating them in various ways
 7. Be able to use particular terms specific to materials science and technology
 8. Apply the powers of observation, measurement, and comparison to analyze materials, their properties and applications
 9. Understand the basic processes of extracting, preparing, and producing materials used in the course
 10. Select materials for specific uses based on the properties, characteristics, and service of the materials
 11. Flourish in an environment of creativity
 12. Think critically to solve problems in manipulating and controlling the materials used in the course
 13. Use writing to record observations, procedures and experiments and as a tool for thinking, studying and learning the subject matter
 14. Demonstrate in writing and discussion an appreciation and understanding of significant developments in the history of materials
 15. Select, design, and build a project or projects demonstrating the creative and innovative application of materials
 16. Work in a cooperative group setting for problem solving.
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Fusing Science and Technology Education

An important aspect of the MST course is how it illustrates the natural “fusion” of science and technology education. Hays (Pacific Northwest Laboratory, 1993) says:

In the MST classroom, the boundaries are blurred between science and technology. It is not easy to know when one ends and the other begins. In this way, the learning environment of MST reflects the scientific and technical enterprise where scientists, engineers, and technologists work together to uncover knowledge and solve problems. In the school environment these overlapping and complementary roles of science and technology are found most often in courses called “technology education” (p. 2.2).

She goes on to say that “taken together, science and technology in the MST classroom are combined to prepare students who not only create, design,

and build, but understand the nature and behavior of the materials used in the building. They have the 'know-why (science)' and 'know-how (technology)' that lead to creativity, ingenuity, and innovation" (p. 2.3)

Methodology

Using observations of classroom and laboratory work, taped student interviews, and student journals, this study describes student perceptions of an MST course. The study took place over an eleven-week period starting in September and ending in November 1992. Classroom visits were conducted two days a week for ten weeks. Three separate classes were observed during each visit. Pseudonyms were used for the teacher and students involved in the study.

Observations

On Thursday, September 24, 11:30 a.m., at the end of the students' lunch period, Desert High is a different place than it was during my first visit. The quiet halls are transformed by the boisterous mix of teenage camaraderie. Mr. Mathews's classroom is a typical educational cubicle. Thirty student desks are crammed into a room built for twenty-four. A ten-foot long table with six chairs around sits in front of the room. Mr. Mathews's desk is wedged into the front left corner. Numerous posters cover the walls. Many are examples of different types and uses of materials. A dozen posters state themes on success or provide thinking prompts: "It's OK to Err"; "What did you do today?"; "Errors are our teacher: I hope you're running fast enough to make some"; "How did it go today? Good or Bad and Why"; and "Success means getting up one more time than you fall down." A large periodic chart hangs on the wall. Book shelves are stacked with books and magazines students use as reference sources. At 11:35, the bell sounds beginning class. Roll is taken by one student as others busily chat.

During roll, Mr. Mathews enters and engages in friendly banter with several students as he passes back assignments, commenting on the work as he goes, "Nice job, Jim," or "This is excellent, Sally." He then proceeds to the back of the room and picks up a student journal. All students are required to keep a journal for the MST class. He spends about six minutes going over various parts of the journal, showing examples of what a journal could look like. He stresses the importance of putting sketches, notes, assignments and projects in the journal. He adds emphasis in saying, "It might be a good idea not to throw your homework in the circular file since that stuff was good stuff. It might be used again on a test, and if you have it in your journal, then it could be a neat reference." He introduces me as "a former chemistry and physics teacher from the other side of the state working at Innovations Inc., and working on an advanced education degree." He tells students I will be observing them for the next couple of months and that I have taught the MST course, though not in the

same way. He concludes his introduction and dismisses them to the laboratory across the hall to work on experiments and projects they have selected.

This is the manner in which most classes begin. Mr. Mathews is there at the bell. He introduces the topic for the day, goes over any necessary details, and then dismisses students to the laboratory, if that is what is scheduled, or continues with the classroom activity he has planned. The banter with students is expected, and students respond to Mr. Mathews's ribbing in a manner demonstrating their comfort with him. Comments made in the student interviews reflect this comfort.

The laboratory, a former industrial arts/technology laboratory about 30 feet wide and 50 feet long, is where students conduct almost all their hands-on activities. Storage cupboards rim the outside perimeter with work space often holding bench top pieces of equipment. A table saw, band saw, wood lathe, and other wood-working equipment are located on the far side of the laboratory. In an alcove at the rear of the laboratory are glass working materials and equipment. An acetylene torch is in the front of the room, away from the door. Four furnaces for melting and a burn-out oven are in the center of the room. In front of the room, equipment for working on metal projects and jewelry is set up on large work tables. Thematic posters are mounted on the walls as well as another periodic chart, this one with a materials emphasis.

As I enter the laboratory, I am surprised at how quickly the students have dispersed to different areas of the laboratory and begin working. They are working in the glass area, in the woods area, and at work tables with a clay called "FIMO" and on wax molds for metals projects. Students love to be in here, and since they are working on projects that they have chosen, they have an intense interest in them.

Moving around the laboratory I notice many students are writing in their journals describing the processes they follow, what works, what doesn't, and asking why. As I circulate from place to place, students look up, sometimes stop working, sometimes continue; occasionally, if they need help, they ask me a question. From the first day, the students are very open. If they have a question, they do not hesitate to ask. Often, if Mr. Mathews is busy, they seek me out to clarify a technique. Beforehand, I learned that Mr. Mathews likes students to do their own research first, so I am careful to determine if they have sought information from someplace or someone before they ask me. Guiding students to help them solve problems themselves is an important part of the MST course.

Interviews

Students from all three MST classes were interviewed. From each class, Mr. Mathews identified an honors student and an educationally disadvantaged student, and I picked four additional students at random, giving me an 18-stu

dent sample population. The interviewees consisted of eleven seniors, three juniors, and four sophomores. Seniors predominated because they have preferential enrollment in the course. Older students were the most verbal, but as always, exceptions existed. Students were candid, open, and often surprised and pleased that I would interview them instead of a "smart kid." What they had to say was informative, insightful, and entertaining.

Examining student perceptions from the foundational works of John Dewey (1938), Jurgen Habermas (1971), and Edwin Farrell (1991) I strongly believe what students say reinforces theoretical assertions. Student responses revealed some wonderful connections.

Findings

The Learning Environment

Teachers often hear, "Why do we have to know this stuff?" This suggests that the lesson is not making any connections for students. To the contrary, students in MST, describe a stimulating class, a place of adventure, or as Mark, a senior, says, "The material in here is complex, but the way it's presented it doesn't even seem like you're really messing around with the stuff you're doing... You just kind of pick it up, and before long you're using big words like vitrification, ionic and covalent bonding, and VanderWall forces...I mean, at first you don't understand it. But you're just kind of picking it up just through using it...It's different than just reading it in the textbook or learning a principle in chemistry. It really opens your learning to the world. You're doing practical stuff, but you're learning big concepts. It really kind of turned me on to science again."

Analyzing Mark's comments you begin to appreciate the learning he has done. Experiences have built on one another. The big concepts have taken shape over time by experiencing them, not by reading about them in a textbook. Rather than simply learning the definition for vitrification, Mark followed the process a scientist would. He mixed ceramic materials and tested the results. He now understands the changes that take place when a material vitrifies. The same thing happened with ionic and covalent bonding, terms commonly used in science. Mark understands them because he has seen the results of their influence on crystal structure, metallic bonding, alloying, grain boundaries, and phase changes. The all-important connections between what is to be learned and the experience have occurred.

One of the unique aspects of the MST course is the use of other students as a reference. This gives students who know how to do something a chance to explain and enhance their understanding of an area while allowing receiving students a chance to learn the material from peers.

Often one student helps others, as in the glass working area where I observed one student demonstrating a particular glass cutting method to another.

Student A: "How did you cut that curved piece? Mine keeps breaking." Student B: "Like this, see." Student B demonstrates the technique from cutting to tapping to breaking the glass. Student B: "Be sure you tap it with this end to get it to crack. Then use these (holds a pair of nipping pliers) to break the glass." Student A: "Oh, that looks easy." Student A then does his piece and Student B watches as he follows her instructions.

A tremendous amount of activity is going on in the laboratory. If the students did not help one another, Mr. Mathews would not be able to allow so many diverse activities to occur simultaneously. Peg, a senior, confirms this saying "You can actually see what they're talking about, and relate that. It's easier to understand if you can see it. It's not just a bunch of diagrams of circles."

Real-World Connections

Learning in MST also means making connections in other ways. Farrell (1991) suggested that students need to make connections between school and jobs or future careers. Andy, a junior, sees just such a relationship between the MST course and the world of work, "This class interests me, it kind of lets you use your imagination. The way I see it, the more we learn about it now then we'll be able to use it more. Like if we want a career." Margo, a senior, suggests the same connection saying, "It gets you your seat of experience. You do stuff here and you can take it out. First of all, you learn responsibility...You get experience with equipment that might get you a job sometime later...It's all up to you."

Real-world connections, understanding from the student's view of the world, is clearly seen in Ken's statement, "Well, I think it's a class where you come and learn about the materials of the world and learn how to apply them to everyday living and how we use them in our everyday lives."

These students have been able to make a connection between what they are learning, future goals, and jobs. For them, the MST course is a significant place where meaningful experiences occur. They are not likely to become drop-outs.

Working in Teams

Research suggests that students also need social connections in their work. Team work is one social connection that often helps students to understand material. Robin, a senior, identifies the importance for her, stating, "The fact that you don't have to sit in a chair all day and just listen to a teacher say do this and do that. You get to pick out what you want to do and when you want to do it. It helps you too, you can team up with someone." This student is verifying several important concepts: being actively involved in the material being studied, participating in the decisions on what is to be learned, and working cooperatively. All three are goals of the MST course.

Hands-on Approach

Dewey (1938) stressed the importance of students making an “organic connection between education and personal experience” (p. 12). He further expounded, “education is a development within, by and for the experiences” (p.17). Applied to the MST course, Margo says it this way, “It provides an atmosphere of hands-on, and for me that's something very different. It's not always an atmosphere that's provided in the schoolroom, and it helps me to learn. To be able to touch it, to feel it, to work with it and to be able to experiment with it. I don't always learn everything I'd like to be able to learn from a book or maybe be able to learn as well from a book.”

Sam reinforces the hands-on approach, “Actually,” he says, “being able to do something, hands-on, the hands-on part, that's what I like. I seem to learn, learn things better, I guess, being able to actually do it instead of learning it out of the textbook--actually doing it.” Karen, likewise, sees MST's hands-on approach as important saying, “I took this so I could use what I do learn instead of just knowing it and taking tests.”

As can be readily seen from student comments, the MST course offers the connections, relevance, and hands-on activities that help make science, mathematics, and technology education viable. From student studies of phase diagrams of alloys to applying the concepts of density to actual applications in making alloys, they appreciate the connections to situations where they can use the principles being taught.

Journals and Student Projects

When asked about the use of journals, another important connection between learning and understanding, students interviewed were able to affirm relevance. Each student found writing has a purpose. It gives them a reference, a focus for problem solving, and a way to think. It is significant that journals are not separate from learning in class. Students use their journals as a tool. Journals help develop Dewey's sensitivity, careful and diligent attitudes, and gathering, integrated, centering habits.

Bob says, “I like it because you can look back and see where you have been, you can see it in case you're lost. I like them because they keep you up to date.” Chuck puts journal use in the MST course this way, “You can look over what you've done, and you can see where you've made mistakes and what to do to improve those.” Robin says, “If you messed up on something, you can look back, see where you went wrong and figure it out.”

Even though students stated during interviews that they did not like writing in the journal, their journals gave engaging insights into their understanding of science and how they learn best. What do students actually write in their

journals? Are journals the tool students claim them to be? Examining journals, I found that indeed they are just that, a tool.

The examples that follow are representative of student writing. Sample journal entries from interviewed students represent one of the better students, an average student, and a student Mr. Mathews indicated was a poor writer. In the first example we follow Ken, a sophomore, as he begins a project.

Ken (9/23): Today I outlined the shape of my key chain on my sheet-wax. I also drew the letter "R" (drawn in his journal) and traced it onto another sheet of paper and then cut it out. I plan to engrave the letter into my wax model on both sides using the paper diagram as a guide. I will then trim my model down to size. After I complete my model, I plan to make a mold in the burnout oven. I will then centrifugally cast sterling silver into the mold and come out with a finished product.

(9/24): Today I proceeded to trim the sheet-wax surrounding my model down before I actually cut the model out. However, when I was trimming the remaining excess wax from the model, the model cracked and one of the corners broke off...I'm going to try and fuse the wax back together tomorrow. If the process doesn't work I will have to make an entirely new model.

(9/30): I continued to shape and engrave my wax model today. Unfortunately it broke. Mr. Mathews wants me to make a new model using pieces of thin sheet-wax stacked on top of each other. (Diagrams are drawn in journal to show this new approach.)

(10/6): I began work on my new model...I hope to finish my model tomorrow.

Ken begins, develops a problem, tries a solution, and finally changes strategies. Everything goes smoothly for Ken as he invests his model and prepares to make the sterling key chain. We rejoin Ken's journal with an entry for calculating the amount of metal needed for his project.

(10/21): Calculating metal density for model

weight of wax	1.7 g
plus 40%	0.68 g
total weight	2.38 g

(does calculations for silver and copper) and enters the following: need 1.9 g of Cu and 23.1 g of Ag.

This entry shows how Ken makes a connection between what density is and how it can be used. He knows the density of his wax is about 1 g/ml and where to look up the density of sterling silver, which he found has a density of about 10.8 g/ml. Using this information, Ken easily determined the amount of silver and copper needed for his project. The concept of density has a useful connection. It is not just a fact to memorize.

This same process gave several other students a lesson in economics. They wanted to make a sterling silver belt buckle. When they had their wax model finished, completed the calculations for the amount of silver needed, and found

the cost, they decided another alloy might be better. Rather than scrap all their hard work, they used another material. They made brass belt buckles.

Ken continues his work and descriptions, developing a new problem.

(10/22): Today Mr. Mathews helped me in my casting process...My key chain came out quite nicely. I plan to file down the engraved side over the weekend.

(10/27): I plan to fill the engraved "R" with a clear green ceramic material because I can't get the engraved surface flat (a drawing shows the problem area).

(11/12): I have begun pouring the ceramic mixture into the engraved portion of my key chain ornament. All has gone well except that the ceramic leaked out of the designated area and became attached to the reverse side of the ornament. I will attempt to sand off the residue tomorrow.

On November 19, I talked to Ken. He said that the previous day he fired the ornament and the ceramic shrank and cracked in the process. He had another problem to solve. As Ken's problem developed, he was exposed to both the physical conditions of the materials and the results of materials interactions. The expansion and contraction rates of dissimilar materials allowed him to see the results on his project. He developed an understanding of hardness as he began to remove the ceramic from the back of the silver piece. Science terms became science realities with meaning.

Looking at student journals you can clearly see that they are always working, learning and thinking--problems arise, and they have to adjust to them. If journals were not used, mistakes made could occur again. Because students keep a record, though, they seldom repeat errors. As they reflect on the materials and use the correct technical terms in their explanations, they attach meaning and understanding to the terms.

Students Teaching Students

Another student, Ory, enters this in his journal:

(11/19): Today I finally cast strange-little man. I had strange-little man cooked at 900^o, I think. Then I put him in the rotating machine. In this I melted my Ag + Cu. (has a drawing here with arrow to help) And cast my medallion. From there I broke out the medallion and kept him. Next I have to sand and polish.

(11/23): Today I helped three people invest their rings. I feel like a Materials Science genius!

This entry is especially important. It shows the impact that one student teaching another has on the student doing the teaching. "Today I feel like a Materials

Science genius!" He went through the process and was able to show someone else how to do it--an excellent example of connecting to his real world.

Peg solves her problems in this excerpt:

(9/16-18): In the lab I am in the process of designing a ring. It will be a gold lion's head clasping an emerald or a green stone. I took a block of purple wax (square) and sawed off the chunk I needed.

(9/23-25): Dan and Margo helped me drill a hole into the wax, but it ended up too small. I tried to file it, but it was still way too small. I cut the block into 2 sections - to get the size I wanted. Taking my pencil, I outlined what I would carve onto the side of the wax.

(9/30-10/2): At this point Mr. Mathews showed me how to wrap wax around and melt it together (a drawing clarifies this). Right now I'm in the process of building up enough wax to form my lion's head.

(10/7): Today I will be using inlay wax to shape the finer details of my lion's face. I will be using 4 different tools (drawings of tools are included). In this hour I completed most of the fine details. One problem I've always had is I'll get one side perfect and the other side won't cooperate.

Peg continues with descriptions of the project on which she is working. One last entry shows how ownership in the project affects the student.

(10/27): Today I added more hair to my lion. I also gave it a beard. Dan said it doesn't look like a lion anymore. That comment didn't bother me because I'm secure with my decision. The hair broke off the left side. Tomorrow I will fix it and start working on putting a jewel in the mouth.

Students do use their journals, and they use them consistently. Their journal entries give you a glimpse of the hands-on and minds-on understanding and learning taking place as the students proceed with their projects--concurrent with the findings of Kalonji (1992). Even though this study does not examine student outcomes, journal entries give a strong indication of active student learning.

Conclusions

Clearly, students respond with enthusiasm to the MST course at Desert High. Their reflections indicate that connections are being made between real life and school. Student choices, cooperative learning, daily journals, and hands-on activities make this class highly student recommended. Judging from twenty years of teaching experience in two states and in five different districts, I do not see the students of Desert High to be significantly different from students at many high schools. They have classes they don't like. Some are bound for college, others are not. One significant difference I did notice was that these MST classes had few discipline problems because students are actively engaged in learning. Neither gender, ethnicity, nor academic predisposition affected

student performance or enthusiasm in this class. Because of the limited scope of this preliminary study, I was not able to observe the students in other classes, so I cannot say that these students were as industrious in all their classes. In fact, several indicated that indeed they were not.

Many questions can be raised from this study about student achievement. Does this class truly allow students to better learn science, mathematics and technology as a result of their participation in the MST class? This study cannot answer that question because its focus was on student attitudes toward science, not outcomes. Students' responses confirm they enjoy science; for many, MST revived positive attitudes toward science. In Mark's words, "It's really interesting...It really brought me back toward the science fields." While few students interviewed will likely pursue science as a major, the majority do feel good about science and appreciate their experiences. This, in itself, is a major step toward developing a science literate society.

This pilot study demonstrates ways that students are learning how science, mathematics and technology and the strategies used--writing, experimenting, designing and building--can help them relate science and technology to their lives. The problem-solving approach, with students making projects of their own choosing, using a hands-on/minds-on strategy, gives all the students a measure of success. Focused through the connections that they have established through ownership, working, and writing, the students talk to each other, help one another, and begin to enjoy learning. Science, mathematics, and technology move from the piecemeal, tedious atmosphere of a text-driven classroom to an adventure, a place to come, explore, and learn. Individual student interests establish projects. Laboratory activities develop concepts. These activities, coupled with group work, and writing, not working in isolation, allow students to share successes and learn from their errors. As they learn, they share, teaching and explaining to one another. Unanticipated results are learning experiences, not something to hide.

MST students are not just learning vocabulary and concepts; they use the terms and ideas to develop understanding. For example, the periodic chart becomes a reference. Bonding is used in relationship to crystalline and amorphous materials. They use the mole concept to calculate the amount of material they need to make a particular type of glass. Ductility, grain boundaries, work hardening, and slip plains develop significance as they draw wire. Phase diagrams and melting points for alloys have applications to the solder they make and use. Students see real life connections between their learning and perceptions, and the jobs that they read about, talk about, hear about, and eventually pursue.

Guest speakers share their experiences and discuss such topics as team work, problem solving, and networking. Students understand the team approach because they have worked together. They realize that there is more than

one way to attack a problem, since they have shared their solutions to problems with one another. They know that each person brings to the team an area of expertise. Some are better with their hands and others with ideas. Some can draw and represent ideas graphically and others in words. Each person can be, and is, a contributor to success.

Dewey's experiences, Farrell's self-as-my-work, and Habermas's particular interests are all reflected in the words, work, and actions of the students in these three Materials Science and Technology classes. The learning theories of today are being applied in the class and the students are clearly responsive as Margo illustrates, stating, "I'm into art, I'm not into math or anything like that. But, I can apply what I've learned here, as far as all the different chemical make ups and nature of materials because they're studying the Stradivarius violin and the finish that they put on the violin and the wood that they used, and now they're trying to replicate that using chemicals and trying to come up with the rich sound and tone. So even in the realm of music you can use it." By listening to what students say, we as educators, using the strategies and concepts of MST, are taking a giant step toward our goal of developing a science literate society.

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