STEM Initiatives: Stimulating Students to Improve Science and Mathematics Achievement

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STEM INITIATIVES
STIMULATING STUDENTS TO IMPROVE SCIENCE AND MATHEMATICS ACHIEVEMENT

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Concepts in science, technology education, and mathematics show powerful relationships when it comes to student learning. By using the context of engineering, additional meaning can be brought to the curriculum and student learning and achievement.

FEATURE ARTICLE

Teachers and subject matter specialists are concerned with improving students' performance during standards testing. Initiatives have been undertaken at the local, state, and national levels in attempts to better enable learners to master new knowledge and perform complex tasks. Curriculum developers and researchers are interested in contextualizing learning situations to associate students with the utility of what one is learning. Transfer learning is being explored within the realm of problem solving and engineering applications. This makes a strong case for the integration of science, technology, and mathematics, so students can improve their understanding and application of complex but usable knowledge.

Learning theorists believe that, through designed learning environments (contexts) and learning with hands-on projects, new knowledge can not only be learned, but learned in such a way that the knowledge can be transferred for other applications (Singley & Anderson, 1989). Student interest and motivation can also be piqued through hands-on learning.

Scholars in the applied sciences (school science, technology, and mathematics) believe that these subjects have transfer among themselves and that engineering activities can establish the contexts to learn these subjects, plus aid in the transfer of knowledge. This collaborative movement is referred to as STEM—integrating instruction in science, technology education, engineering, and mathematics. It has been a focus of National Science Foundation research on learning and student career choices in the sciences and engineering.

According to American Society for Mechanical Engineering:

> There appears to be a logical educational continuum within which the knowledge of science, technology, engineering, and mathematics is cumulative. This implies that, without a strong and vibrant K-12 education system, the potential educational and economic impact is severely diminished. Yet…the cumulative benefits of science, technology, engineering, and mathematics are less than they could be (ASME Position Statement – 2002, ID #2-32, www.asme/org/gric/ps/2002/02-32.html, March 24, 2004).

Through academic collaborations of mathematics, science, and technology education in a contextual engineering environment, programs should:

1. Build cumulative STEM competencies in students by building on the foundation of knowledge established at each level in education, from elementary grades where students have innate curiosity about their world and how it works through middle school, high school, and beyond.
2. Provide students with hands-on, open-ended, real-world problem-solving experiences that are linked to the curriculum, using science, engineering, and technology modules, and grouping such experiences and modules by discipline and level of difficulty.
3. Promote hands-on activities for students, including research-oriented classes…appealing to students through authentic [contextual] research projects that emphasize the use of mathematics in reporting results, and promoting engineering and technology…in high school (ASME Position

Statement – 2002, ID #2-32, www.asme.org/gric/ps/2002/02-32.html, March 24, 2004).

STEM is recognized in the science, education, and engineering professions and their associated research societies. It is a unique way to map curriculum and attempt to build and strengthen student skills in those subjects that can lead to scientific and technological career pursuits. This is the authors' intent with this writing. We wish to show how the school subjects of science, technology education, and mathematics can be taught in collaboration and use engineering concepts and activities to motivate students to succeed.

Science, technology education, and mathematics have had standards developed by their professions and endorsed by such prestigious organizations as the National Academies of Science and Engineering. Teachers, textbook writers, and educational hardware and software companies are using these standards. They also serve as the basis for state standards tests. For more information on the national standards, conduct a Web search for *National Science Education Standards* (1996), *Standards for Technological Literacy: Content for the Study of Technology* (2000/2002), and *Principles and Standards for School Mathematics*, (2000).

Subject Integration and Support

Many school systems are requiring the study of algebra in the ninth grade. For this and other reasons, the authors decided to work with the subjects of earth science, algebra, and foundations of technology and use engineering concepts and activities to create standards-based learning activities. The authors will show how we have used contextual learning and concept mapping to assist us in our endeavors.

Contextual Learning

The predominant view of learning today posits that "people construct new knowledge and understandings based on what they already know and believe" (Bransford, Brown, & Cocking, 1999, p. 10). This philosophy, known as constructivism, is based on the foundations laid by John Dewey, Jean Piaget, Lev Vygotsky, and other educators. Constructivist teachers actively engage students in a variety of ways. In fact, national research on recognized mathematics and science teachers show that they utilize five strategies:

- Relating – learning in the context of one's life experiences or preexisting knowledge.
- Experiencing – learning by doing, or through exploration, discovery, and invention.
- Applying – learning by putting the concepts to use.

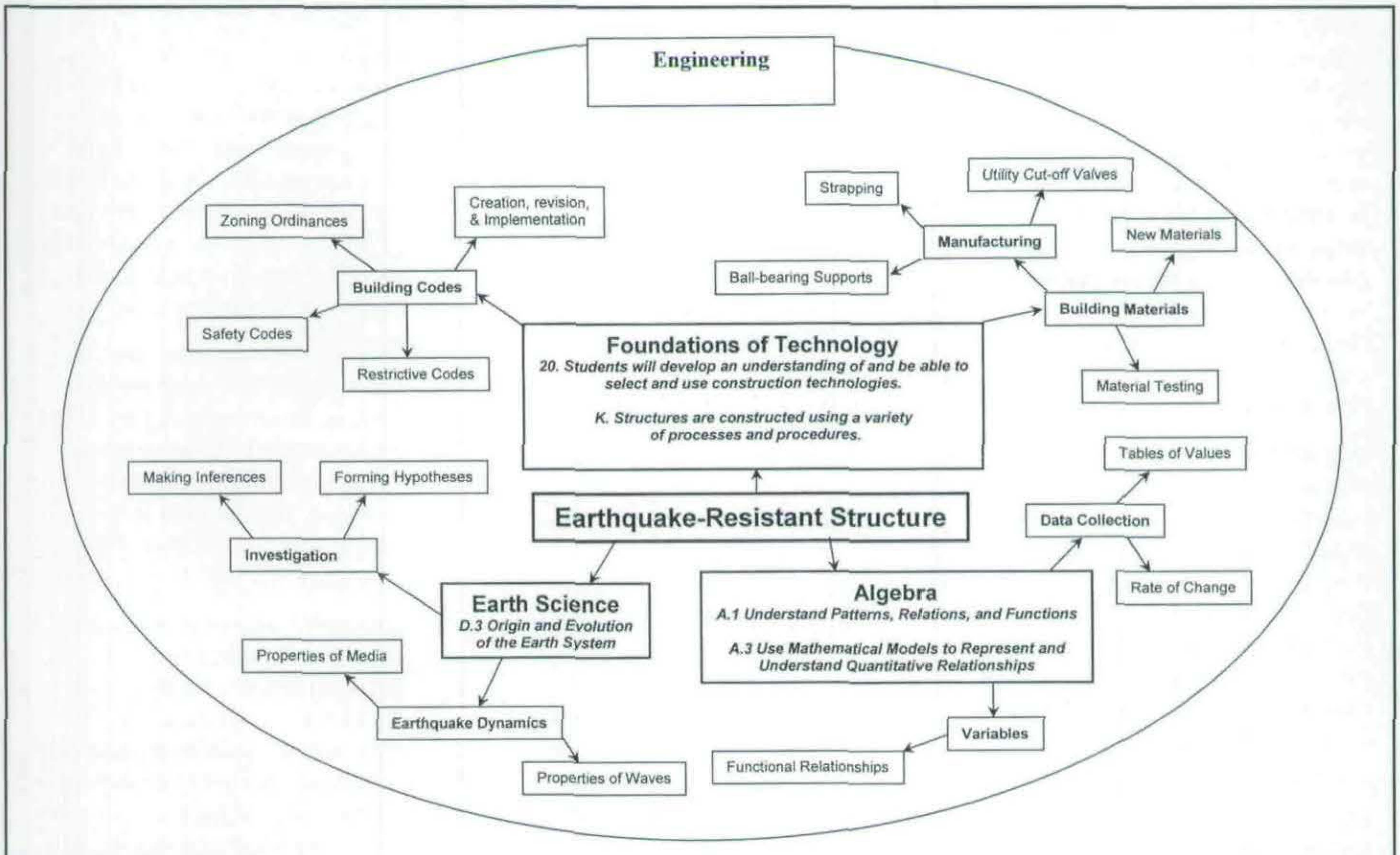

Figure 1. Concept Map of a Science, Technology, Engineering, and Mathematics (STEM) Activity

- Cooperating – learning in the context of sharing, responding, and communicating with other learners.
- Transferring – using knowledge in a new context or novel situation—one that has not been covered in class (Crawford, 2001, p. iii).

The Center for Occupational Research and Development (CORD) identified these five strategies (REACT) as contextual learning strategies because they help teachers put teaching and learning into context. CORD has developed a series of resources on contextual learning that are research-based and include classroom lessons (see CORD, 1999a and b).

The first two REACT strategies are the most important and lie at the root of constructivist methodology. If students do not relate learning to existing knowledge and experiences, then higher levels of learning will be difficult to achieve. Applying, cooperating, and transferring are the three levels that STEM initiatives unite. Concept mapping illustrates these REACT strategies in a visual manner that can help teachers plan for instruction. See Figure 1.

Aligning and Integrating Science, Technology Education, and Mathematics Content

Alignment of the standards in Earth Science, Algebra, and the technological literacy standards in Foundations of Technology courses illustrates the means through which contextual learning can address content standards in the three subject areas. With respect to student understanding of the origin and evolution of the earth system, the emphasis is on student understanding of the ongoing dynamic equilibrium of earth that results in both short-term and long-term change on earth. Key ideas include the relationship between the dynamic crust and atmosphere, the resulting environment, and the environment's impact on life.

Mathematics is key to students' understanding of how the earth originated and its change over time through micro-scale activities, which allow students to concretely explore resulting phenomena within a dynamic, evolving earth system. Through micro-scale activities, students quantify this change over time, recognize patterns and relationships, and come to understand that mathematics can be a useful way of representing ideas via functions that can be graphed, charted, and represented through other graphic organizers. In this case, technology education plays a pivotal role in terms of data collection tools and aiding humans in their understanding of the dynamic earth so that informed decisions can be made. An example of a micro-scale activity related to the dynamic earth is the design and construction of structures capable of surviving a simulated earthquake. Through this engineering experience, students learn not only the principles of design and construction, but also principles of earthquakes in terms of wave and media properties that can then be quantified at the micro-level and extrapolated to decisions regarding current and proposed architectural plans.

As reviewed in this discussion, concepts in science, technology education, and mathematics show powerful relationships when it comes to student learning. With each of these subjects, transfer learning is very natural. By using the context of engineering, additional meaning can be brought to the curriculum and student learning and achievement.

The Importance of Engineering

Engineering is "the profession in which knowledge of the mathematical and natural sciences…are applied…to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind" (ABET, 1979). It can also be stated that engineering is the means by which people make possible the realization of human dreams by extending our reach in the real world (Babcock & Morse, 2002). It is composed of multiple fields such as electrical, mechanical, chemical, civil, etc. engineering, which use science, mathematics, and technology to reach these outcomes. Engineers are the practitioners of the art of managing the application of science, mathematics, and technology.

Integration of Science, Technology, and Mathematics through Engineering Activities

There are two types of activities that these authors have developed to assist students in learning science, technology education, and mathematics content through engineering activities. These include introductory activities that are quick and create excitement for the upcoming unit of study. Some disciplines refer to these as experimenting activities. Again, examples would include those suggested in Table 1. An experimenting activity for earthquakes could be breaking a candy bar, such as a Milky Way™, by pushing it together or twisting it. This would show how the earth layers are moved by such forces.

The second type of activities that we suggest is unit or applying activities. These take longer to develop and for students to participate in their completion. In this article, we have developed a unit activity that used a constructed device to measure the effects of earthquakes on structures.

Earthquake Activity

The following unit, or applying activity, is one sample of STEM initiatives designed and developed for the purpose of integrating science, technology education, and

Table 1. Correlation of Standards for Earth Science, Algebra, and Foundations of Technology

Earth Science	Algebra	Foundations of Technology	Sample STEM Activity
D.1 Energy in the Earth System	A.1 Understand Patterns, Relations, and Functions	16. Students will develop an understanding of and be able to select and use energy and power technologies. 16.J Energy cannot be created nor destroyed; however, it can be converted from one form to another.	Energy can be measured over time, and rates of change in temperature can be measured in terms of the variables that influence the rate of change (for example, wind. Students can cut paper spirals and attach them to a string. Use a flashlight to produce heat to move the spiral.)
D.2 Geochemical Cycles	A.1 Understand Patterns, Relations, and Functions A.4 Analyze Change in Various Contexts	3. *Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.* 3.J Technological progress promotes the advancement of science and mathematics.	Rate of change with respect to changes that occur to elements within the geochemical cycle over time (for example, rock cycle, which describes the relationship between different types of rocks via applying pressure and heat to corn starch putty).
			Graphic representation of rates of change with respect to changes that occur to elements within the geochemical cycle over time (for example, mass of sedimentary rock via erosion through chalk soaking in vinegar).
D.3 Origin and Evolution of the Earth System	A.1 Understand Patterns, Relations, and Functions A.3 Use Mathematical Models to Represent and Understand Quantitative Relationships	3.J Technological progress promotes the advancement of science and mathematics. 5. Students will develop an understanding of the effects of technology on the environment. 5.I With the aid of technology, various aspects of the environment can be monitored to provide information for decision-making.	Rate of change as measured by radioactive decay is expressed exponentially (for example, fossil dating).
			Atmospheric and geological data are used to determine the age and history of the earth based on reasonable conclusions drawn from quantitative measures and are used to predict future events (for example, rate of sedimentation and layers of rock or geologic events such as earthquakes. Break layered candy bars to simulate the cracking of the earth's surface).
D.4 Origin and Evolution of the Universe	A.3 Use Mathematical Models to Represent and Understand Quantitative Relationships	3.J Technological progress promotes the advancement of science and mathematics. 5.I With the aid of technology, various aspects of the environment can be monitored to provide information for decision-making.	Space/Time data are used to determine the age of the universe based on reasonable conclusions drawn from quantitative measures (for example, measure of expansion of a substance containing raisins).

Note: Numbers have been assigned to standards for communication purposes. The *Standards for Technological Literacy* document (ITEA, 2000/2002) has assigned these numbers.

mathematics through different hands-on engineering activities to improve learners' understanding and interest in science. It is the result of science, mathematics, and technology educators working with engineers to show how engineering can synthesize the academic content so important to helping students make reality out of theoretical knowledge.

Engineering Project:

Earthquake Simulation – Measurement and Prevention

Goal: Experiment/learn the effect that earthquake displacement and its resulting twist angles have on building structures and resulting destruction.

Activity:

1. Construct the testing apparatus using the pictures (Figures 2 and 3) and materials list.
2. Use K'NEX Primer Set to construct three different shapes of building structures (three stories and a base size of 6").
3. Obtain different linear plots until the destruction of these three shapes occurs.
   a. Place one or two food cans inside the top of the structure.
   b. Pull the moving table in X or Y directions to a recorded displacement value (inch units), then let the bungee cords retract and bounce the moving table.
      i. Allow for three tries each or until the structures collapse.
      ii. Obtain three plots of the linear displacement for reliability.
      iii. Obtain different twisted angular plots until the destruction of these three shapes (pull base to 45 degrees and to distinct retraceable routes).
4. Determine the strength of different shapes of the structures vs. different displacements and twist angles.
5. Predict and recommend the shapes vs. earthquake destruction (construct hypotheses).

Science Relationship: Origin and Evolution of Earth Systems

Technology Education Relationship: Design, Construction Technology

Math Relationship: Equality, Inequality, Statistics

Suggested Experiment/Construction Material List:

1. 1 plywood base - ¾" x 4' x 4'
2. 1 plywood section for moving table - ½" x 10" x 10"
3. 4 pieces of wood to form the sides of the moving table - 1" x 2"x 10"
4. 4 pieces of wood to form the sides of the base frame - 1" x 6" x 4'
5. 8 eye hooks for elastic bungee connection
6. 4 bungee cords for elastic bouncing
7. 3 ball casters to support moving table
8. 2 holding mechanisms to support the plotting pens' position (holes through the supported platform will do, but a top needs to be in place to hold the pens down)
9. 1 K'NEX Primer Set for structure construction or other construction sets, i.e., Lego
10. 2 regular pens for tracing displacement recordings
11. White card stock for padding the tracing table
12. Several graphing sheets for recording the moving table traces
13. Wood screws for construction
14. Two different-sized unopened food cans for structure destruction tests (Resemble elevators, water tower, or boilers within the building)

Material Cost: Approximately $40.00 from local home center

Figures 2 and 3 present the fully assembled and constructed earthquake simulation platform and moving table with plot pen-holding mechanisms.

Figure 2. Platform, Moving Table, and Structure

Figure 3. Moving Table and Plot Pen Holders

The Calculations and Hypotheses

The plot pen holder mechanism designed for this experimental moving table can be easily substituted with a 90^{0} angle made of wood (Figure 3). A regular ball pen with spring tension that is adjustable with a collar and setscrew will provide enough tension for better plotting on the moving traces.

The moving plots presented in Figures 6 and 8 are hand re-traces of the original table movements for better visibility. The linear displacement plots (Figure 5) have equal lengths in the X and Y axes. This means there is no twist angle involved. The twist displacement plots (Figures 6 and 7) have different lengths in both the X and Y axes. This means there is a degree of twist angle involved.

According to the experimentations, the most destructive damage to the simulated building structure is the

Figures 4 and 5 show a linear movement of X or Y-axes plots during an earthquake simulation.

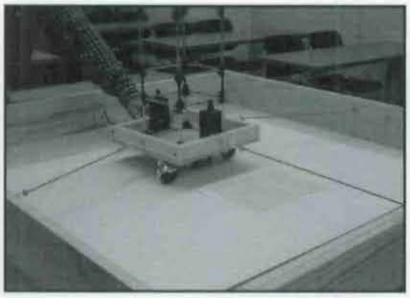

Figure 4. Table Linear Displacement

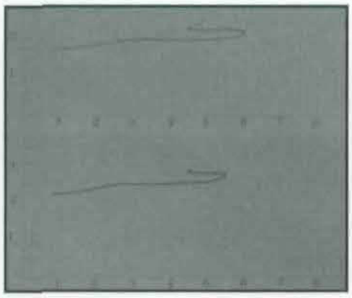

Figure 5. Linear Displacement Plots

Figures 6 and 7 show the curved movement of X and Y-axes displacement plots that produce twist angles on the Z-axis during an earthquake simulation.

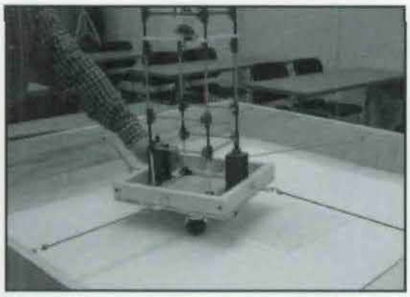

Figure 6. Table Twist Displacement

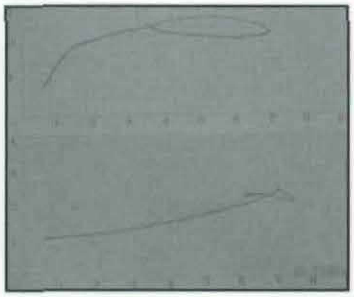

Figure 7. Twist Angle Displacement Plots

movement with twist angles. The force displacement is based on the calculation: F (Force) = K (Bungee Cord Spring Constant) x X (Displacement); and the energy calculation is based on: K (Kinetic Energy) = ? K (Bungee Cord Spring Constant) x X^2 (Displacement^2) (Hu, Liu, & Dong, 1996). Due to the design constraint, the twist angle in this simulation does not include the up and down motion (Z axis). There are twist angles on X, Y, and Z-axes, and any combination of those create the harshest damages from natural earthquakes on buildings.

Summary

Activities can be used to increase students' understanding of knowledge in science, technology education, and mathematics. By using such activities, students apply different intelligences. Through hands-on learning using engineering activities, students should be able to gain more knowledge and transfer this learning among school subjects. The science and engineering communities are familiar with STEM initiatives. Through these activities, educators may notice that students' standards test scores can improve.

References

American Society of Mechanical Engineering. (2002). *Position statement – 2002*. Retrieved March 24, 2004. from http://www.asme.org/gric/ps/2002/02-32.html

Babcock, D. & Morse, L. (2002). *Managing engineering and technology*. Englewood Cliffs, NJ: Prentice-Hall.

Bransford, J. D., Brown, A.L., & Cocking, R.R. (Eds). (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Bjork, R.A. & Richardson-Klavhen, A. (1989). On the puzzling relationship between environmental context and human memory. In C. Izana (Ed.) *Current Issues in Cognitive Processes: The Tulane Floweree Symposium on Cognition* (pp. 313-344). Hillsdale, NJ: Erlbaum.

Cormier, S. & Hagman, J. (1987). *Transfer of learning*. San Diego, CA: Academic Press.

CORD. (1999a). *Teaching mathematics contextually*. Retrieved April 8, 2004, from www.cord.org/lev2.cfm/87

CORD. (1999b). *Teaching science contextually*. Retrieved April 8, 2004, from www.cord.org/lev2.cfm/87

Crawford, M.L. (2001). *Teaching contextually: Research, rationale, and techniques for improving student motivation and achievement in mathematics and science*. Waco, TX: CCI Publishing, Inc.

Hu, Y-X., Liu, S-C., & Dong, W. (1996). *Earthquake engineering*. London: Chapman & Hall.

International Technology Education Association. (2000/2002). *Standards for technological literacy: Content for the Study of Technology*. Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Research Council. (1996). *National science education standards*. , DC: National Academy Press.

Singley, M.K., & Anderson, J.R. (1989). *Transfer of cognitive skill*. Cambridge, MA: Harvard University Press.

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