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THE MWM APPROACH TO TECHNOLOGICAL DESIGN

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ABSTRACT

The term *technological design* first appeared as central to one of the Content Standards in the National Science Education Standards[1]. It has recently been replaced and clarified in the draft version of the latest national science education standards entitled Framework for Science Education[2]. The term that has emerged in the draft standards document is *engineering design*. In this paper the term technological design is meant to be reciprocal with the new term engineering design. Most science teachers are unfamiliar with the technological design content standard, and most districts have yet to include technological design in the canon of their secondary science curricula. This article describes in detail what the MWM program proposes as an approach to understanding and incorporating technological design as a process of thinking that complements the scientific process. The MWM program provides a platform for science education to integrate science with engineering, technology, and society through design projects. The objective is to bring potential users to the threshold of technological design in an organized and intuitive manner. As a result, teachers can maximize concept retention by having students engage in hands-on projects that demonstrate how science can be applied to the solution of everyday problems.

INTRODUCTION

When science is taught with a real world, hands-on, student centered, cutting edge focus, students respond in ways you may never have thought possible. Consider these actual examples of MWM inspired design projects that students in typical science classrooms around the country have conceived, designed, tested, produced, re-designed, re-tested, and reported on. Students learned the chemical and physical properties of fire proof, lightweight roofing shingles; of Frisbees™ that create their own light as they move through the air; of polymers that protect and nourish a flower; and of boats that float when made of concrete. When science learning has a compelling connection to the real world, when it evokes endless possibilities, when the evaluation incorporates authentic assessment of the design process, when students are taking charge of their own investigations in order to create something that they envisioned, students learn! They learn more, they retain it longer, they enjoy the experience, and they understand a little better the interconnectedness of science, engineering, technology, and society. The key to these outcomes is the deliberate integration of science content with the practices of scientific investigation and design processes. This article describes the process that the MWM program uses to provide a realistic approach to technological design in the science classroom.

INTEGRATING CONTENT WITH THE SCIENTIFIC AND DESIGN PROCESSES

MWM 2002 uses the scientific process together with the technological design process to bring about added dimensions of content acquisition for science students. In reality, of course, secondary students are not yet accomplished practicing scientists. They are novices learning novel material. Therefore, as Roblyer et al.[3] emphasized, discovery learning in the beginning should be strategically incorporated and carefully structured because it is important for students to build a cognitive reserve of reliable experiences from which to draw for later experiences. Students therefore become more accomplished over time. Unfortunately many educators assume that design should be a stand alone experience. This, in part, may be because technological design as described in the National Science Education Standards[1] assumes that students have already acquired the basic science concepts and skills. Technological design should never be so loosely structured or open-ended that students become frustrated, lost, or unable to explain their work. It is most important that inquiry activities never lead to false or misleading ideas. The MWM approach guards against such misuse. The modules prepare students with four to five lead-up investigations that teach the science concepts students will need to complete the final design projects. In this way, MWM presents a balanced approach. The modules contain elements of direct instruction (readings and questions) plus guided inquiry. Later, open-ended inquiry is introduced in an appropriate manner. Thus, MWM provides secondary students with early experiences that reflect how scientists and engineers actually incorporate technological design into their everyday work.

THE SCIENTIFIC PROCESS vs. TECHNOLOGICAL DESIGN

Although technological design incorporates aspects of inquiry in general, the main difference between the scientific process and the technological design process is the goal. The scientific process seeks to understand, conceptualize, and explain natural phenomena as theory. The technological design process, on the other hand, applies theory to the creation of new phenomenon or is used to make modifications to what already exists in order to better meet societal or consumer needs. Roth[4] described the differences as a reciprocal relationship between abstract symbol and phenomenon. The scientific process seeks to translate observed phenomena into symbols e.g. mathematical equations or system models, whereas the technological process translates (applies) theoretical symbols into phenomena or product development.

In an attempt to arrive at a clearer understanding of technological design, the table below sets inquiry apart from problem solving. Inquiry is defined theoretically as being implied only in the scientific process whereas problem solving is used only in the practical application of the technological design process. In the reality of everyday practice, the situation is not quite so clearly defined.

Technological design is not limited to only one strand of work. There are two types of technological design: *product and process.* A product design, as the name implies, refers to the development of a usable artifact. In some circles, such as the automotive industry, aesthetic design becomes an important feature of product development. A process design refers to a set of procedures, processes, or steps that can improve an existing practice, e.g. traffic patterns, assembly line procedures, or a new process for recycling waste.

Table 1. A Distinction Between the Scientific Process and the Technological Design Process

Steps of the Scientific Process (Inquiry)	**Steps of Technological Design (Problem Solving)**
Purpose: To create or replicate theory that explains phenomena in the natural world.	Purpose: To propose solutions to technical problems or to make modifications in what exists in order to better meet societal or consumer needs.
• Observe/ question/ wonder about a phenomena. • Develop a researchable question. • Conduct a literature search. • Propose a hypothesis. • Select a research design. • Identify independent variables, dependent variables and controls as applicable. • Plan the methodological details (sample size, treatment plan, equipment set-up, etc.). • Conduct the investigation and collect data. • Analyze and display data. • Interpret findings. • Draw conclusions to support/not support the hypothesis. • Discuss findings and state implications for future research. • Write the report and publish where appropriate.	• Recognize a need. • Create an initial definition of the problem. • Articulate the design constraints. • Gather information from a literature search or from pilot observations. • Revise the problem statement based on the new information. • Brainstorm possible solutions or iterations (Many possible solutions, many competing hypotheses, many "correct" answers…) • Choose a course of action based on available resources. • Create a prototype(s) or model(s). • Test and assess each solution /prototype/ model. • Evaluate the possible solutions and select the most feasible given the design constraints. • Communicate the results (oral or written) to an audience of stakeholders or clients.

As can be seen from Table 1, there are features that overlap the scientific process and technological design, but there are also differences[1, 5, 6, 7, 8]. For example, the scientific process usually deals with one dependent variable at a time and retains that variable until a conclusion is reached. The process of technological design is more open. The investigator may consider or take into consideration any number of plausible variables at appropriate times. While there may be technical differences, it must be emphasized that neither the scientific process nor technological design actually occurs in a rigid sequence of defined steps. Creative ideas and new insights often change the course of a project's direction.

STUDENT READINESS FOR TECHNOLOGICAL DESIGN

MWM 2002 is designed to bring students to the threshold of technological design in an organized and intuitive manner. One of the major advantages of the program is that each student automatically enters a module experience at his or her own unique level of ability or readiness. Therefore, what follows is an authentic build onto previous content and process knowledge. As teachers circulate from team to team and listen to student conversations they gain valuable insights into their students' logical reasoning processes. Teachers are able to evaluate how well their students communicate with each other as well as the depth of their content knowledge. Teachers have reported that technological design provides a unique opportunity to listen in as one student explains, in student language, the nature of a concept to a fellow student struggling to find understanding.

As students work through the opening activity or "hook" of an MWM module, they first experience the scientific process in the form of guided inquiry. Additional content is learned through short readings and review questions that clarify the relevant concepts. Over the course of one week, students acquire the basic science or materials science concepts that will be applied to the culminating design project. The design project is often revealed at the very beginning of the sequence to focus the activities that follow. At the same time, students advance through increasingly more sophisticated levels of inquiry in the form of investigations and, if appropriate, possibly open-ended inquiry. Then, during the second week, as they undertake a design project, students switch from the scientific process and follow the technological design process. But during the technological phase of work, when students test a prototype, they will return once again to the scientific process to test the performance of their design or its component parts. As an additional bonus, it often happens that as students test and modify their designs, they will revisit and solidify previously learned concepts.

THE MWM APPROACH TO TECHNOLOGICAL DESIGN

The primary goal of technological design in the MWM program is to help students apply and reinforce science and mathematical content knowledge by participating in the process of creating, modifying, or building something that solves a problem or meets a perceived need. The MWM approach echoes the position of Lewis[5] who argued for the inclusion of technological design in science classes as well as the inclusion of science concepts in technology education classes.

The MWM program defines technological design as a series of six component activities each creating laboratory opportunities that encourage students (a) to express themselves individually as well as in a group; (b) to better observe and communicate their activities; and (c) to engage in iterative trials that improve understanding and thinking. The program places a special emphasis on iterative trials because redesign can best cement an understanding of the scientific concepts and focus attention on the practical considerations that affect the success of a design. By doing so, students experience the reinforcement of content knowledge, process skills, and technological reasoning.

The six major components emphasized by MWM align with the National Science Education Standards[1] and the Standards for Technological Literacy of the International Technology Education Association[6]. The MWM program, however, goes beyond these standards by including the component of *"Redesign"* as seen below.

The six major components with targeted learning objectives are:

The Problem
- Define the problem
- Gather background scientific information

Design Implementation
- Brainstorm ideas
- Propose prototype(s)
- Design the prototype(s)
- Construct the prototype(s)

Test
- Devise and conduct tests of the prototype (s)
- Reflect on the feasibility of the prototype design (s)

Redesign
- Propose alternate design for prototypes (if needed)
- Implement the redesigned prototype(s)

- Test the redesigned prototype(s)
- Reflect on the feasibility of the newly designed prototype(s)

Evaluation
- Develop evaluation criteria
- Choose the best design
- Evaluate the design solution and its consequences using the criteria
- Identify the pros and cons for each design
- Decide why the design that was chosen was the best choice

Communication - using verbal, written, portfolio, or dimensional models,
- Communicate the problem
- Describe the processes/ procedures used
- Visually display the test results
- Identify the "best" solution and tell why
- Discuss the feasibility of the design in the real world e.g. a marketing or business plan
- Reflect on what was learned from technological design

From experience, most teachers would concur that every student who engages in a design project will take on differing sets of attitudes and skills from their experience. In other words, it is not likely that everyone will acquire all of the new behaviors possible. Nonetheless, the MWM approach to technological design is structured to enhance student acquisition of many of the characteristics associated with learning. Below is a list of learning behaviors reported by MWM 2002 field test teachers[9].

- Piquing an interest in science and technology
- Improving teamwork skills
- Sharing responsibilities
- Appreciating the role of science in the real world
- Knowing how things work in the man-made world
- Knowing how things work in the natural world
- Overcoming a fear of failure
- Understanding concepts as opposed to memorizing them
- Applying learned content knowledge in a new context
- Willing to take risks in order to advance an idea
- Being willing to pursue a new direction
- Discovering and improving one's new talents and skills
- Making decisions based on criteria and data
- Understanding the importance of controlled and varied parameters
- Experiencing the reality of no "right answer"; look for a "best answer"
- Developing the skills of innovation
- Thinking in unconstrained ways aka "outside the box"
- Appreciating critical feedback

TEACHER MANAGEMENT OF SUCCESSFUL DESIGN PROJECTS

When teachers use MWM modules, they are compelled to use classroom management strategies that research has identified as linked with successful design based activity[10, 11]. Furthermore, 118 teachers in a national study of a later version of MWM, known as MWM 2002[9], along with those teachers who frequently use MWM materials, report being more successful if they:

- Assure that students have essential and sufficient content/background knowledge
- Switch from an authoritarian role to that of a facilitator or project collaborator.
- Make sure students have a clear understanding of their design goal or problem.
- Decide whether students should choose their own groups or be in teacher assigned groups.
- Create class guidelines of "professional courtesy" for giving commentary on the work of others.
- Start each class session with a few minutes of organizational suggestions, words of

encouragement, or behaviors to be avoided.

- Emphasize experimental design by carefully choosing variables to test that can best inform students about their design rather than having students resort to mindless trial and error.
- Help students deal with failure by assuring them that they cannot fail or be wrong as long as they try their best and document their efforts.
- Manage the class by circulating from group to group and asking nonthreatening questions about what students are attempting to do.
- Use conversational or a lower tone of voice during discussions with teams or when giving commentary.
- Emphasize that competition is not the primary objective; rather a good design is.
- Encourage the completion of at least two design iterations.
- Draw out what students are thinking using probes such as, "Have you thought about...?" "What if you tried ...?"
- Achieve a classroom working hum as opposed to a status of student noises that indicate a haphazard or silly approach to lab work.
- Make sure that all students/teams receive feedback on their designs and presentation.
- Coach students in the components of making an effective presentation using Power Point, film, or other visual media.
- Coach student teams on how to present an effective oral or written report of their work
- Encourage students, when needed, to seek outside expertise and advice from the business, higher education, research, or other professional community.

ASSESSMENT OF STUDENT DESIGN PROJECTS

The MWM program acknowledges teachers as the intellectual leaders of their classrooms. In practice, teachers and students are usually more confident with design projects if teachers think of assessment as a road map to what is to be learned and create rubrics that act as milestones for guiding student progress. More importantly, it is wise to involve students in the creation of design rubrics, whether in suggesting components or in validating what their teacher proposes.

Because no two classes are ever alike, teachers are encouraged to teach design projects according to their goals for each class. Those goals and accompanying rubrics should be shared with the class at the start of the project. It is likely that the same teacher may have differing goals for each of the classes he/she teaches. For example, suppose a teacher may have a goal to improve scientific communication skills in one class. The teacher would then emphasize and give higher point values to a team's written work or to its presentation before an audience. In such a case, the amount of detail in the rubric's corresponding goal would expand to include all the applicable features a teacher would want to observe. For another class, the same teacher may want to emphasize the application of one or two science concepts. In that case, the teacher would expand the rubric to assure that students addressed elements such as literature search, scientific explanations, data tables, or depictions. Besides addressing teacher goals, every set of evaluation rubrics should be drafted based on the amount of available time, the maturity level of a class, the amount of previous essential knowledge acquired by the class, as well as the previous experience the class has had with the processes of lab investigation and technological design.

The MWM program offers teachers a set of generic rubrics to guide the creation of customized rubrics. The six MWM design components listed earlier have been expanded into ten instructional goals shown in Table 2. Teachers are free to reword, add, or delete items listed for each design goal. In addition, teachers are encouraged to weight point values for each goal according to what they expect students to gain from the experience. Later, if desired, point values can be translated into

Table 2. A Guide to Creating Customized Rubrics for Assessing Design Projects
Note: Each of the 10 design goals is assigned point values according to the teacher's goals for the class. When added point values should equal 100.

DESIGN GOALS	CRITERIA OPTIONS	ASSIGNED POINT VALUES
1. The Problem	Clear /accurate statement of the problem Evidence of plausible reasoning	
2. Background Knowledge	Evidence of concept knowledge Evidence of literature or internet search	
3. Initial Design	Brainstorm initial ideas for prototypes Identify design constraints Develop prototypes	
4. Test	Plan an investigation Identify appropriate variables Collect data Display data Analyze data Draw conclusion	
5. Redesign	Brainstorm alternate prototypes Identify design constraints Develop prototypes	
6. Retest	Plan an investigation Identify appropriate variables Collect data Display data Analyze data Draw conclusion	
7. Evaluation	Select best design Cite reasons for the selection Align selected design with design constraints	
8. Prepare Presentation	Statement of the problem Design constraints Procedures Evaluation Impact of the design	
9. Reflection	New information learned New process skills acquired Issues / problems addressed or resolved	
10. Presentation (oral/written/media rich)	Content accuracy Organization of the presentation Clarity of the presentation	
		100 points

letter grades according to desired categories of point values, e.g. (90-100 = A; 80-89 = B), etc. Some teachers format rubrics so they are able to check off elements on the rubric sheet as they circulate among and meet with teams during class time. That way, students can track their own success throughout the project.

SUMMARY

Technological design is not simply an intuitive process, although intuition may play a part. Finding solutions to complex problems will always be a challenging intellectual activity because there may be many answers, none of which may be readily obvious, especially to novice designers such as high school students. It is important for students to gain an appreciation that there is more to design than simple trial and error. Some observers have even said that project learning is hard to implement[12, 13]. This is certainly the case when teachers and students are not sufficiently prepared. We have found that teachers and students feel more secure when, in the beginning, they are guided through the fundamentals of design. They must practice it and carve out the necessary amount of time for its implementation. For that reason, MWM makes an ideal supplement to secondary science. The modules can be used in whole or part, but in order to achieve maximum results, teachers need to include the design challenge(s) at the end of each module. As both teachers and students gain experience with design, they will experience a dosage effect in which previous experience begins to compound itself. Above all, students learn what to expect. Therefore, it is important that teachers assure that their students, from the beginning, have sufficient content knowledge, sufficient time, reasonable goals, and targeted reflective experiences. And like that of experienced scientists in the real world, technical innovation is a challenge made feasible when science knowledge, science processes, and technological design come together. We have concluded that the MWM approach provides a perfect entry system for teachers and students to technological design.

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