AC 2008-641: INVENTION, INNOVATION AND INQUIRY - ENGINEERING DESIGN FOR CHILDREN

Daniel Engstrom, ITEA/Cal U

Dr. Engstrom is an associate professor and principal investigator for Invention, Innovation, and Inquiry. He has written national curriculum that integrates science, mathematics, and engineering with technology education. He currently works in teacher preparation in technology education at Cal U

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Abstract

This preservation will focus on the NSF funded project entitled Invention, Innovation & Inquiry (I^3). It will highlight how the project was formulated, the materials developed, results of field testing and implementation, and future activities. Special attention will be given to how the I^3 project emphasizes the integration of science, technology, engineering, and mathematics in each unit as student follow an engineering design process to solve a technological challenge. The I^3 program has developed 10 units of instruction that focus on the development of technological literacy traits for students in grades 4-6.

The study of engineering has increasingly become more prominent in K-12 public education. This emphasis on design and problem solving through applied mathematics and inquiry based science are at the center of the National Science Foundation funded project entitled Invention, Innovation, and Inquiry (I3). This project is so named because invention and innovation are the hallmarks of technological thinking and action. This article will describe the background of the project, how the units of instruction were developed, field testing procedures, findings, and finally discuss how this curriculum has been implemented in various settings.

The purpose of the I3 project was to write ten thematic units that focused on developing technological literacy in students, grades 5-6; creating teaching and learning resources based on selected technological and science literacy standards; and disseminating the units to teachers in training workshops and distance learning. Each unit has standards-based content, suggested teaching approaches, and detailed learning activities including brainstorming, visualizing, testing, refining, and assessing technological designs. Students learn how inventions, innovations, and systems are created and how technology becomes part of people's lives.

The primary goals of the project were to:

1. Create a model for standards-based instructional units addressing the study of technology and science to be implemented in grades 5 and/or 6.
2. Align contemporary classroom/laboratory instruction with technological literacy and science education standards and with connections to mathematics standards.
3. Pilot and assess the model in diverse classroom/laboratory environments.
4. Disseminate resources with professional development support.

To write each unit, a strict process was followed that reflected the Understanding byDesign (UbD) approach created by Wiggins and McTighe[1]. This process has three main steps including identify desired results, determine acceptable evidence, and then design learning experiences. This process is important to follow to ensure that educational standards are clearly uncovered and appropriate assessments are developed prior to the learning experiences.

Unit Development

The writers met as a team to discuss the unit development process and select a unit to write as described in the grant proposal. Careful attention was given to ensure that mathematics, science, and technology content was integrated and aligned to appropriate standards. And that the unit was developed following the UbD process. In each unit, careful attention was given to alignment to the *Standards for Technological Literacy: Content for the Study of Technology*[2]. Once the conceptual framework was developed and agreed upon by the writing team and the project director, a draft version was written. Each writer then conducted a meeting with at least ten teachers. This meeting helped to further focus the unit and provided the writer with a sounding board and additional ideas. Finally, the unit was further developed and a peer-review process between the writers was undertaken. The peer review process helped to ensure that all units were being written in a similar manner and that all materials was being covered.

Engineering Design Process

In addition to the content, it was important that all units followed the same engineering design process. This process contained five primary steps including:
Identify a Challenge – This is usually the first step of the innovation process. Students should realize the importance of carefully examining existing products to identify their limitations. This is a key step of innovation. An example would be the telephone and how it has changed and improved because people wanted it to be smaller, lighter, more mobile, faster and more attractive.

Explore Ideas – This step is designed to enable students to brainstorm ideas to innovate the product. It is important that students understand that they should come up with as many ideas as possible. The ideas could be sketched and/or written.

Plan and Develop – In this phase students should begin by making a final sketch of their idea. Encourage students to add notes and sizes as applicable. This is also a good time to distinguish between a mock-up and a prototype. Students will also be gathering tools and materials to construct a new product. Some will be brought from home while others are available in the classroom.

Test and Evaluate – In this step students will be completing two tasks. First, they should make sure their new product works as it was intended. In addition they should find out if their product would be accepted on the market by asking other people what they think of it. This can be done with other students or friends and family outside of class.

Present the Solution – This the final step in the innovation process, and many times it leads back to step 1: Identify a Challenge. During this step students should give a short presentation/demonstration to the class of their product.

Unit Content Review

The initial review of the units was done by a team of experts from the field of engineering, science, technology education, and mathematics. This team reviewed all the units and paid particular attention that their particular content material was represented accurately and that the corresponding pedagogy and assessments were appropriate. The project director and lead editor also reviewed each unit. Finally, the experts, lead editor, and project director met to synthesize the findings and make suggestions to the writers. To conclude this phase, each unit was laid out in preparation for the field testing.

Field Testing

Each unit was sent to three teachers for pilot testing. Each teacher was in either fifth or sixth grade and taught technology education. The material was to be reviewed, implemented, and evaluated. This evaluation focused slightly more on the technological content and processes. To obtain information from the pilot test sites each pilot test teacher was required to complete an initial evaluation of the unit based solely on a read-through. While conducting the unit, teachers made notes within the unit document. A final review survey was completed once the classroom experience was complete. In addition to the data supplied through the review forms, teachers sent

samples of student work, site visits, interviews, digital photos of students engaged in the unit, and recommendations made by students about the unit structure. The student work included two samples from each of the following groups: high, average, and low achieving students. Site visits included observation of student activities, an interview with the field test teacher and, if possible, an interview with a building administrator.

Following revisions made by the project director and lead editor, further field testing was done with teachers in self-contained and gifted classrooms. Each unit was then sent to at least five teachers who have little or no background in delivering instructional units dealing with technological design. The feedback material was reviewed, implemented, and evaluated. This phase was conducted twice for each unit. Teachers also implemented a pre/post and authentic post assessment procedure.

Unit Evaluation and Dissemination

Once the units were complete, they were made available electronically and as hard copy through ITEA. A variety of workshops and training sessions were conducted as well as a marketing campaign was implemented in appropriate publications. In addition, five curriculum specialists were trained on how to implement workshops for all ten units. These individuals are currently available and actively conducting workshops and seminars.

Assessment of Learning

Pre/Post Test – This test consisted of fifteen multiple-choice questions. The questions were written at the application level of Bloom's cognitive taxonomy and included questions dealing with science, mathematics, and technology. An item analysis was conducted for each test question and the exam further refined for each phase of unit testing. This assessment is now part of each unit package.
Authentic Post Test – This end of unit assessment was developed by the external evaluation to determine the extent to which unit goals were retained following the completion of the unit. This assessment was authentic in nature, whereby a design challenge, similar to the one from the unit, was given. Students were asked to design/sketch a solution and describe the process they would use to solve the design challenge. The results were scored by independent raters using a rubric. This assessment is now part of each unit package.
Unit Rubrics – In each unit, rubrics were given to assist the teacher in accurately assessing student materials. Throughout the pilot and field testing phases, teachers provided feedback necessary to improve and refine each rubric.

I3 Units

The ten units developed are listed below and are accompanied by a short description.

Innovation: Inches, Feet and Hands
This unit is about innovation, measurement, and anthropometrics, which is the study of the size of human form. Students will be using an engineering design process to design and develop an improved product that is used by the human hand. They will be studying the sizes of the human

hand and using these measurements to estimate sizes of various objects. They will also be improving their measurement ability through various activities.

Invention: The Invention Crusade
This unit will help students in Grades 5 and 6 to explore the process of developing an idea into an invention. Students are asked to invent and construct a working model or prototype of a gadget that will help a small child to do a household task. The culminating event is a "Kids Better Living Home Show" where the young inventors will explain their ideas behind their gadget and give other elementary students an opportunity to try the new inventions.

Manufacturing: The Fudgeville Crisis
Students will explore and identify how the process and preservation of food has changed over time and will see how raw materials can be processed into fudge. Throughout the unit students will be divided into four different teams and each team will become a different company. Each company will experiment with how material can be formed to keep a desired shape, how food can be packaged to keep it fresh, and the importance of cleanliness in a food production environment. As a culminating activity, each team will mass-produce and package their fudge for a fudge festival.

Construction: Buildings and Beams
In this unit students act as structural engineers. The students will design and construct at least two laminated paper beams. They will explore forces that act on structures and discover that the strength of a beam varies with height, shape, and thickness. Lastly, they will test, evaluate, and revise their beams using feedback from testing to refine their designs.

Transportation: Across the United States
In this unit students will explore transportation technology by understanding transportation environments (land, water, air, and space) and transportation systems. They will be able to experience how ideas for inventions and innovations are modeled and recognize how transportation has played an important role in the development of the United States.

Communication: From Print to Radio
Few things have changed our world as drastically as communication technologies, such as the telephone and television. They have changed our homes, our workplaces, and our buying choices. Designing, creating, and producing commercials will show students how to work within the communications environment to create a unique and appealing commercial, or advertisement, to promote school spirit. In this unit students will explore communication processes and mediums by designing, developing, and implementing different types of commercial projects promoting school spirit. In teams of three or four, students will create an advertising firm. Each team will create an identity for their firm and meet their school's advertising needs in order to encourage students to support their school and show school spirit.

Power and Energy: The Wizards of Willing Wind
This unit presents an alternative form of energy that is both available and inexhaustible. Students will construct a device that will capture wind energy and convert it into mechanical energy. The students will also design and build a structure that will support their wind energy device. The

students will research and compare the energy cycles of the most common resources used to produce electricity in an attempt to gain an understanding of how those systems work. The students will also examine the ways energy is used for technological devices in their home.

Inquiry: The Ultimate School Bag
In this unit the students assume the role of design engineers for a company called Sensible School Supplies. They will use inquiry skills to investigate and evaluate the school bags they currently use and apply what they discover to design and construct a model of their version of the ultimate school bag. The students will then present their school bag designs to students from other classes.

Technological Systems: Creating Mechanical Motion
In this unit, students will explore simple machines and linkage mechanisms. After seeing what these can accomplish, students will be challenged to design a toy that uses both to create movement. Since everyone thinks of toys and games as fun, this is an ideal medium for learning. As students turn their ideas into models, learning occurs. Students will design, build, test and make improvements to their designs.

Design: Toying with Technology
This unit will show students how they take an idea from brainstorming to sketching to prototyping. Students will see how creative designs, unique logos, vivid color schemes, and celebrity endorsements can affect how many people may buy, sell, and play with board games. Students will explore two-dimensional (2-D) and three-dimensional (3-D) visualization processes and mediums by designing, developing, and building a board game. Students will design and create a game for the Happyland Toy Company, a fictitious board game company.

Findings

The ten units developed through the I^3 project were effective in teaching students unit content, vocabulary, and technological skills and concepts. Overall, findings point to the understanding and application of the Engineering Design Process as a key benefit of the I^3 curriculum units. This was a central component of all units and this finding supports the goals and objectives of the project.

Teachers' perceptions of the units were extremely positive throughout the development process and improved as revisions were made. Teachers' reviews reflected very positively on the content of the units including teacher background material, goals and objectives, student worksheets, student assessments, and layout of the units. Teacher reviews also revealed that teachers viewed student interest as high, saw design challenges as effective, and perceived them to align with standards. The technological concept survey completed in the final phase of development indicated that teachers were teaching technological concepts not previously covered. Some of the greatest benefits teachers perceived for students included understanding the engineering design process, working in a group, understanding of technology, and problem solving.

Effectiveness of the units on student learning is shown by the pre-test/ post-test results and examples of student work. Students scored higher on post-tests than pre-test indicating their

understanding of unit content. In addition, the project director has numerous and varied examples of student work that demonstrates students' understanding and application of the Engineering Design Process. This work supports teacher perceptions that the students did learn skills such as using the Engineering Design Process, thinking skills, problem solving, planning skills, use of materials, vocabulary, and sketching ideas. Numerous examples of student use of these skills were evident in the work teachers submitted. It was clear that students worked through the steps of the design process to solve design challenges.

Findings from the Invention-Innovation-Inquiry project can be summarized in more detail into three main areas. These are student learning, teacher perceptions, and technological concepts covered. A brief summary is provided first while detailed analysis is provided subsequently for each year of the project.

Student Learning

Pretest/Posttest data indicate that students did improve in their understanding of unit material. T-test analysis showed that students scored significantly higher on the unit posttest compared to pretest for all units. The highest mean differences between pretests and posttests were on the Communication and Construction units. The lowest mean difference was found on the Technological Systems unit.

Examples of student work submitted by teachers showed evidence of the application of the engineering design process. Examples of student brainstorming, planning, sketching ideas, developing solutions, constructing, evaluating, and retesting are all provided.

Teacher Perceptions

Field-test teacher final unit review ratings on fifteen criteria improved as the units progressed through the various phases of the project. This is significant since the objective of this final review was to aid in the revision of the units. Overall teachers rated the I^3 units highly.

Teachers were asked to identify the skills and knowledge learned by students through the I^3 unit. Through the various piloting and field testing phases of this project the following skills/knowledge were consistently identified most frequently. In the final phase of field testing (year 5), at least half of field test teachers perceived these students to have learned these skills through the I^3 unit they taught.

- Using the Engineering Design Process
- Thinking Skills
- Problem Solving
- Planning Skills
- Use of Materials
- Vocabulary
- Sketching Ideas
- Oral Communication Skills
- Written Communication Skills
- Cooperative Skills

- Using Technology
- Journaling
- Math Skills
- Assessing Technology
- Scientific Inquiry Skills

Teachers were also asked to identify three key benefits to students of the I^3 unit. Several key benefits were noted consistently and most frequently by teachers throughout the piloting and field testing phases of this project. These were as follows:

- Understanding and applying the Engineering Design Process
- Working in Group
- Understanding of Technology
- Problem solving
- Constructing/Building a product
- Creative Thinking/Creativity
- Real World Application of Learning
- Integration of Subjects
- Student Excitement
- Learning New Vocabulary

Comments from teachers from early phases of the project in focus groups and in later phases from written comments on final reviews confirmed that they saw the key benefits of the I^3 units to be those noted above. Teachers consistently commented that learning and applying the engineering design process, working in groups, creativity, and problem solving were major benefits of these units.

Technological Concept Survey

The technological concept survey was given in year 5 during the final phase of field testing the units. Data indicated that fifteen technological concepts were covered to a greater extent by I^3 curriculum than field test teachers' current curriculum. In other words, students learned technological concepts through the I^3 units that they might not otherwise have learned. Paired t-test analyses showed that teachers perceived I^3 units to cover all fifteen technological concepts to a significantly greater extent than their current curriculum. This finding points to a need for elementary education to include more technology education units such as I^3 so students understand concepts such as the Engineering Design Process, designing, constructing, problem solving, and technology. Many of these concepts were taught through hands-on learning and both field test teachers and students praised this approach by providing oral comments during site visits and written comments on review forms.

This was a very important finding and plans are being made to use the Technological Concept survey in further research. If this finding can be generalized, it definitely would have an impact on technology curriculum development for elementary schools. In addition, it emphasizes the need for instructional units like I^3 in the elementary classroom, adding substantial credibility and rationale for the I^3 project.

The I3 Project continues to grow. In Florida, a teacher has been assigned to fully train and help fifth grade teachers implement the curriculum. In Pennsylvania, the entire state saw the value in the curriculum and bought a state cite-license so all certified teachers can obtain the curriculum at no cost. Components of the curriculum are being implemented into a variety of pre-service teacher education programs. Finally, as the project grows, additional support materials is being developed to help teachers implement it on a broader scope.

[1] McTighe, J. & Wiggins, G. (1999). The understanding by design handbook. Alexandria, VA: ASCD.
[2] International Technology Education Association. (2000). Standards for technological literacy: Content for the study of technology. Reston, Virginia: Author.