Toys, Tinkerers, and Tomorrow: Growing Engineers

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Abstract

This paper presents the findings and recommendations resulting from a pilot program aimed at educating and interesting middle school students in the fields of math, science, and engineering. "The Joy of Engineering" was piloted in the summer semester of 2000 and included a staff of three multidisciplinary instructors supplemented by 7 middle school teachers from the local school system. There were two one-week sessions offered with a total of 64 students, who were allowed to choose between two focuses of instruction: structures or energy. Two parallelsessions used K'NEX sets as educational manipulatives to teach engineering design concepts with well-defined constraints and goals, and at the end of the week, the students participated in a competition between design alternatives. A structurestrack had students using K'NEX Bridge sets to design and build alternative bridge like structures with a goal of minimizing materials costs while maximizing strength-to-weight ratio. A motion-and-energy-track used K'NEX Racer Energy sets building spring and rubber band powered vehicles with a goal of minimizing materials while traversing a distance in the minimum time. Each track included fundamental concepts necessary to understand forces and limited engineering principles.

Instruction in the program was based on cognitive principles of active and collaborative learning, and, in addition to the technical skills, students were exposed to technical writing strategies and communication skills. The assessment plan included pre/post surveys, student and instructor journals, and an exit skills test. A longevity follow-up study is planned for the spring 2001 semester.

Results were overwhelmingly positive from the program's administrators, instructors, and students, and tips for generalization of the program with recommendations for improvement are included.

I. What is the Joy of Engineering Program About?

The pilot program for The Joy of Engineering Summer Program was created with the primary goal of generating new knowledge and excitement about the fields of math, science, and engineering for middle school students. Two separate one-week sessions were offered June 12-16, 2000 and June 26-30 at The University of Memphis' Herff College of Engineering, and each day's session was scheduled from 9:00 a.m. until 3:00 p.m.

II. Project Goals and Objectives

This pilot program was designed with the major goal of bringing a sense of fun and creativity to the fields of math, science, and engineering, and the project was based around three main objectives:

- To introduce student participants to math, science, and engineering principles in a context-based environment with the opportunity to develop cognitive awareness through a hands-on learning environment
- To interest and educate teacher participants by modeling innovative instructional methods of teaching math, science, and engineering principles with high-tech manipulatives linked to current research-based theories of education. Additionally, the program faculty seek to model instruction of problem solving and critical thinking methodologies which these teachers can extend and modify to their own classrooms
- To lay the groundwork for the program faculty to increase community interest and awareness in university-level opportunities to learn about the fields of math, science, and engineering through this program. The program faculty want to show student and teacher participants that math, science, and engineering careers can be much more than just work!

III. Project Design

The pedagogical design of The Joy of Engineering program is based on the principles of educational psychology and cognitive learning theory. Research in these areas indicates that high levels of student learning and student motivation are possible in psychologically active learning environments[1,2,3] As engineering educators in higher education, all instructors in this program are experienced educational researchers in this genre, and many of the principles that are successful for college students have also been demonstrated to produce success with middle school students. We also patterned our curricular approach to model previously successful similar programs[4,5], with modifications for our own program. One example of a customization is our inclusion of writing instruction integrated with the technical content of the program. Because research has demonstrated a strong connection between the transfer of skills from content to writing to application, we designed our instruction to reflect this knowledge[6].

Most of the current curricular modifications are based on primary principles of cognitive educational psychology that urge educators to focus first on individual learning styles and then on curricular delivery[1,2]. In addition, the most successful programs are those which employ a variety of approaches designed to work in tandem to appeal to different learning styles. Randolph's[3] recent examination of Kolb's[1] and Bloom's[2] ideas regarding individual learning styles suggests that engineering educators should design curricular methodologies centered around the needs of the students. At the same time, Randoloph[3] proposes that writing can be used as a powerful tool for learning by appealing to these different learning styles when the instructor considers the individual learning styles of the students. If these findings from applied classroom research are connected with basic cognitive learning theories presented in educational psychology that capitalize on the individual learner's ability to make meaning and then transfer that meaning to practical applications, it would follow that our students might transfer this new knowledge into their regular classrooms in the form of increased motivation and increased interest in science and math classes[7,8,9,10].

With the previous literature and research studies in mind, we designed our plot sections with the primary curricular goal to create and adjust instructional methods to suit the individual learning styles and needs of our students. The following sections provide additional details.

IV. Project Format

Each day of our 5-day program followed a consistent format with the introduction of one or two new concepts and then the implementation of these concepts in a project each day. The daily schedule was:

- 9:00-9:30 Introduction, review, and writing. Journals were distributed to each student and teacher for keeping up with scientific data through journal entries, observation notes, and project planning. At the end of each day, the faculty would collect and respond to the students with qualitative (narrative-based) feedback.
- 9:30-10:30 Introduction to theory, principles, and design. The students were divided into small groups for the design section of the program. Each group selected a group name and a group slogan, and this section of the course focused on introducing the students to the basic content and theory by explicitly linking theories with hands-on examples.
- 10:45-11:45 Planning, plotting, and design in groups. The groups used this time each day to practice the skills they'd learned in the earlier session by designing prototypes of bridges and racecars. Like practicing scientists, the students first wrote individual plans for design in their journals, then discussed their ideas with their group members and selected a group model for design. At the end of the hour, each group presented and tested their design to the rest of the class.
- 11:45-12:30 Lunch
- 12:30-1:00 Group-building and problem-solving activities. These problem-solving activities were designed to promote team cohesiveness and to teach innovative problem solving techniques. While they may look like simple fun, there's always a curricular goal. For example, just above, it looks like the students are simply flying paper airplanes…what they're really doing is learning to modify and adjust design and construction issues based on project parameters. Sometimes they need the planes to stay in the air for a specific amount of time; other times, they design planes to travel a specific distance.
- 1:00-2:00 Group design projects. Once the students had an introduction to the fundamentals, they worked together in their groups to achieve specific design parameters.
- 2:00-2:30 Group presentations and testing. Each group was required to give a presentation of each day's major design with an introduction to the group members, a summary of the project specifications, a rationale for the design, and the results and recommendations based on the test data. These presentations were videotaped, and the videotapes were available to the students for review and assistance in planning for the next presentation.

- 2:30-3:00 Wrap-up and writing. At the end of each day, students were asked to answer specific questions in their journals. Some questions asked about content knowledge; others focused on group dynamics; and all writing activities urged the students to write entries directly to the program faculty. The journals were collected at the end of the day and the program faculty responded to them in writing and returned them to the students the next day.

V. Project Results

Research data was collected from the student and teacher participants by the program faculty through the administration of surveys and the analysis of journal entries. A copy of the exit survey is included at the back of this report.

Surveys were administered to students on the last day of each program at the beginning of the session. Questions were designed to evaluate the students' perception regarding the amount of learning and satisfaction with this learning in the fields of math, engineering, and writing. As Tables 1, 2, and 3 demonstrate, the results were significantly positive.

Table 1. Learning Total Excerpts from the Exit Survey

	Lots	Something Every Day	Some	Very Little
How much math information do you believe that you really learned in this program?	28%	40%	28%	4%
How much about engineering do you believe you have really learned in this program?	64%	20%	16%	

Table 2. Attitude Excerpts from Exit Survey

	Engineering is more interesting to me than it was before	Engineering is about what I expected	Engineering is not for me
How has your attitude toward engineering been changed by this program?	28%	40%	28%

Table 3. Student Perception Excerpts

	Yes	No
Did writing in your journals help you organize or plan your designs?	88%	12%
Would you be interested in attending other programs similar to this one?	92%	8%
Would you like to come back next year and study what the other track studied?	88%	12%
Would you recommend this program to your friends?	96%	4%
Has anything that you've learned in the program made you want to study harder in math and science?	76%	24%
Before this program, had you ever done group work in science, math or writing?	92%	8%
Do you like working in a group?	88%	12%

We interpret these findings as significantly positive in light of the fact that the findings and comments were student-generated in a voluntary program. These children received no compensation or school credit for attending the program, so there would have been no reason for deceptive results on the exit surveys.

VI. Qualitative Data collected from the student surveys

In order to verify our quantitative findings and seek more detailed information about student perception and student response to The Joy of Engineering, we also collected qualitative research data in the form of narrative question/answer formats. The following excerpts represent qualitative, hand-written comments from our student participants:

Sample questions and answers:

Question: How does writing fit with math and science?

- "It fits by brainstorming on how to do something. We had a writing teacher so she could see how well we write."
- " . . .when you make observations…(you write)".
- "It helps you understand more".
- "You have to put math and science terms so they can be understood by kids".
- "I think it fits because math and science both require a lot of writing".
- "Organization. I believe there is a writing teacher to show us how to organize".
- "We would have the knowledge to know how to write and what and why we are writing about it".

Question: How can you take what you've learned about problem solving back to your regular classroom?

- "By using the problem-solving paradigm".
- "By starting from the bottom up".
- "I'll use it in math or science when I need it or in other subjects too".
- "It helps with study, preparation, and decision skills".
- "Use it in similar problems".

- "In planning".
- "By using it in school like for solutions".
- "If we work in groups, it will be easier".
- "By talking about all the things we have done in this program".

VII. Conclusions and Recommendations

The Joy of Engineering 2000's pilot program was successful in many ways:

- The program achieved the stated goals and objectives as measured by the survey instruments and final products produced by the students
- The program successfully introduced and interested middle school students and their teachers in pursuing additional knowledge about science, math, and engineering careers

- The program's faculty worked together to model group and individual problem-solving strategies which can be used in the students' regular classrooms
- From the students' responses, there was a significant increase in the amount of knowledge about the engineering profession
- A generally positive attitude toward the utilization of math and science was noted and a willingness to focus on those topics as a preparation for a career in engineering or science was also seen

The pilot program of Joy of Engineering 2000 provided a stimulating and active learning environment to 56 middle-school students interested in learning more about math and science as applied to the field of engineering. The initial research results were strongly positive, and the university instructors involved with the program were also quite enthusiastic about the program's results.

Suggestions for expanding the program for next year include:

- Add a student worker to assist program instructors with copying and data collection tasks
- Revise the "Introduction to Engineering" section at the first of the course to focus more on introductory activities and hands-on concept learning
- Cap each class at 16 students to allow small group projects
- Consider asking the teacher-participants to model group learning and problem solving by working on the same projects with the same constraints. Benefit here is that none of the student groups would have the addition of teacher-directed design ideas in their own constructions
- Provide Program T-shirts to each participant
- Consider integrating new program topics on a 2-tier program—the 2000participants would be eligible to enroll in the new topic sections first if they maintained certain levels of achievement throughout the academic year
- Integrate computers into the program for use with word processing, presentations, and computation
- Expand the topics considered to include tracks with an emphasis on computer usage and simple programming skills. The use of simple robotic devices such as LEGO's Mindstorms is suggested.

For more information on this program, contact Paul Palazolo at ppalazol@memphis.edu.

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Anna Phillips is Director of Technical Communications for the Herff College of Engineering at The University of Memphis in Memphis, Tennessee, and she’s also an active instructor and researcher in the Civil Engineering Foundation sequence. As a technical writing instructor with a background in educational psychology, her contribution to this project is based on the team-teaming collaborative environment associated with the Sooner City Project customized to expand the areas of technical communication for undergraduate engineering students.

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Charles V. Camp is the Bobby Warton Professor of Civil Engineering at The University of Memphis. He received his B.S. and M.S. from Auburn University and his Ph.D. from Oklahoma State University. He is a member of the development and teaching team for the introductory sequence of courses in the Civil Engineering department in addition to teaching courses in structural engineering at both the undergraduate and graduate level.

Assessment Instruments, Joy of Engineering Program, 2000

Exit Survey: Joy of Engineering Summer Program

Name:________________________ Age: ____ School:_________________

Purpose: This survey is designed so you can give feedback about this program directly to the instructors and sponsors of the program. Your answers are confidential, and this means that we will collect the surveys in an envelope, seal the envelope, and we won't look at your answers until the program ends. Do not worry about making any of us or our sponsors upset by your answers—your opinions are important. Thanks for your help.

Program Questions

How much science information do you believe you have really learned in this program?

__Very little __Some __Something every day ___Lots

How much math information do you believe you have really learned in this program?

__Very little __Some __Something every day ___Lots

Did writing in your journals help you organize or plan your bridge/car designs? __Yes __No

Which of the following statements do you agree with?

__Engineering is more interesting to me than it was before
__Engineering is about what I expected
__Engineering is not for me

Perception Questions

What would you describe as your favorite thing about this program?

What would you describe as something you'd like to change about this program? How would you change it?

Would you be interested in attending other programs similar to this one? __Yes __No

Would you recommend this program to your friends? __Yes __No

Has anything you've learned in this program made you want to study math or science in college?
___Yes __No

How does writing fit with math and science? Why do you think this program had a writing teacher too?

Are there any comments you'd like to make about any of the instructors in this program?

Problem Solving Questions

How much information do you believe you have learned about problem solving in this program?
__Very little __Some __Something every day ___Lots

How can you take what you've learned about problem solving back to your regular classrooms?

Group Work Questions

Before this program, had you ever done group work in science, math, or writing? __Yes __No

Did you like working in a group? __Yes ___No
Explain your answer:

What's the best thing you can say about your group?

What's the biggest problem you've had with your group?

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BRIDGE QUESTIONS

1. Draw and label the parts of an arch bridge:
2. Draw and label the parts of a suspension bridge:
3. Bridges in our competition were scored on _____________ and ______________
4. What is the SWR of a bridge?
5. Draw and label something symmetrical and something asymmetrical:

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ENERGY IN MOTION QUESTIONS

1. Speed is ____________ per _____________.
2. A variable that YOU control is called a _______________________.
3. Why would you use a bar graph in a report or presentation about your cars?
4. Name 2 criteria your final cars will be judged by in today's competition:
   1.