Engineering Principles for High School Students[1]

Mike Robinson	M. Sami Fadali	J. Carr	C. Maddux
Curriculum & Instruction	Electrical Engineering	Science Teacher	Counseling & Ed. Psy.
University of Nevada	University of Nevada	Hug High School	University of Nevada
Reno, NV 89557	Reno, NV 89557	Reno, NV 89512	Reno, NV 89557

Abstract- *This paper gives some background information and the results of teacher attitudes toward engineering from a capstone engineering course for pre service and in service science and mathematics teachers. The course was designed with collaboration from the colleges of engineering and education to increase the interest of high school students in careers in engineering. The course, Science and Technology for High School Teachers, was taught for the first time in the fall of '98. It was designed to increase the awareness and competence in various areas of engineering of high school science and mathematics pre service and in service teachers. The paper also reports the pre test and post test results of a three-week science unit on engineering principles and design that was taught by one of the teachers in the capstone course. The results of the study indicate that more knowledge of engineering makes attitudes of high school students more favorable toward engineering.*

I. Introduction

The 1996 NSF report [1] identified the need for a well trained work force and better student preparation before entering college as urgent national problems. Conventional wisdom is that to overcome these problems, students must be more motivated and prepared in high school programs. In international comparison in mathematics and science the US does not compare favorably with other industrialized countries [5]. Furthermore, most current teacher training programs in the US do not provide the motivation, attitudes or adequate training to high school science and mathematics teachers to enable them to prepare their students for careers in engineering and technology. It follows that better preparation of high school teachers and more exposure to engineering and technology are required.

To this end, we designed a new engineering capstone course for high school teachers [4]. The engineering capstone course addresses the following questions: 1. How can secondary science and mathematics teachers be trained to have both the motivation and knowledge to include engineering content knowledge and problem solving skills in their classes? 2. How can secondary high school and mathematics teachers be trained with the skills needed to revise existing mathematics and science courses and to develop new ones with more engineering principles and design?

The capstone course was taught for the first time in the fall of '98. This paper addresses three areas that relate to the course. First, a brief description of the course is given including its strengths, its weaknesses, and directions for improving the course based on the experience gained from teaching it.

Second, the paper provides information about the attitudes toward engineering of the first students who took the course. At the beginning of the course the students were given a 25-question attitude scale about engineering and what engineers do. The paper presents the results of that survey. The following research questions are addressed: 1) Did the attitudes of the secondary pre service and in service science and mathematics teachers become more favorable toward engineering after the capstone course? 2) Are the attitudes of secondary pre service and in service science and mathematics teachers more favorable toward engineering than a convenience sample of other secondary pre service and in service secondary teachers?

Last, the paper reports the pretest and posttest results of a three-week science unit on engineering principles and design that was taught by one of the teachers in the capstone course. The following research questions are addressed: 1) Were the student posttest attitudes toward engineering more favorable than the pretest attitudes? 2) Were the posttest attitudes of the treatment group more favorable toward engineering that the posttest attitudes of the control group?

II. The Capstone Course

We have developed a capstone course to introduce secondary education majors to engineering practice. The course is required for graduating secondary science and mathematics pre service teachers during their senior year and prior to student teaching. With some additional assignments, it is also available for graduate credit for returning science and mathematics teachers working on graduate degrees. The course introduces the pre service and in service teachers to engineering problem solving through specific practical applications. It includes the following: (1) projects to be completed by teams of students; (2) lectures by the instructors and guest lecturers; (3) activities

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performed by practicing engineers and students; and (4) the related ethical, social and environmental issues within the rubric of Science, Technology and Society (STS). It emphasizes science literacy and inquiry learning, the two main goals suggested by the recent *National Science Education Standards* [3]. Teaching models that incorporate the constructivist learning model [6] and the five domains of the STS teaching method [7] are also used in the course.

The course furthers the goal of teaching students to become problem solvers by emphasizing an introduction to the practice of engineering rather than its theory. The course sets up problems, presents simplified solutions and avoids complex theoretical developments. The course follows the model presented in an earlier paper by the authors [4].

The contents of the course as taught in 1998 are given in the web page
http://coeweb.engr.unr.edu/classes/engr491.html
As is often the case with new and evolving courses, the course was a learning experience for the instructors as well as for the students. One problem is that the wide variations in topics, student background, and lecturer background, made it difficult to judge the appropriate level of the material to be presented. In several sections of the course, the instructors overestimated student preparation and presented material that required more time for explanation and left little time for student activities. Thus, the lectures by faculty and practicing engineers, which were meant to complement the topics addressed in the projects, were too lengthy and reduced the time for projects. The instructors that were less ambitious in their material selection were able to adhere to the original course plan and focus on student projects and activities as originally intended. Instructors who were unable to adhere to the course plan have indicated that the experience has taught them what is realistically achievable for the intended audience and have already revised their material accordingly.

The lectures emphasized the importance of ethical, social, economic and political issues in engineering practice. They included experimental demonstrations or viewing of videotapes when appropriate. For example, discussions of structures subject to potential earthquakes were complemented by tapes of actual earthquakes, air photographs, geologic and soil maps as well as an earthquake building shaking demo. The ethical, political and economic aspects of projects to build such structures in an urban setting were also discussed.

One field trip was part of the course. The trip was to International Gaming Technology (IGT) and students got a first hand look at the design and manufacturing of slot machines. The company employs over 100 engineers in computer, electrical and mechanical engineering. Students were able to talk to the chief engineer of the company about the changing technology of slot machines to incorporate the latest computer technology. An especially interesting part of the field trip was a discussion and demonstration of some of the many ways that "cheats" try to beat the machines and the countermeasures that IGT must build into the machines.

Last, the pre service teachers learned how to modify existing secondary science and mathematics courses with the infusion of engineering curricula. The altered courses may include units as short as three weeks infused into existing courses or completely new one semester classes built around engineering and technology principles and applications. The intent of both types of course is to motivate and better prepare secondary students for possible SME&T careers. This model, to the authors' knowledge, is a rare attempt to exploit the vast experience of high school teachers to integrate high school and college education in technology and engineering. Many earlier attempts have concentrated on the pedagogical aspect of teaching teachers rather than aiding them in developing content based courses suitable for their audiences and environments. We believe that this new model to prepare pre service and in service secondary science and mathematics teachers can be implemented in universities throughout the US.

Next, we discuss pre test and post test results of the engineering attitude scale given to the students in the capstone course. The following two research questions are addressed: 1) Did the attitudes of secondary pre service and in service science and mathematics teachers toward engineering become more favorable after the capstone course? 2. Are the attitudes of secondary pre service and in service science and mathematics teachers more favorable toward engineering than a convenience sample of other secondary pre service and in service secondary teachers?

II.1 Method

A one-group pretest-posttest design [2] was used to measure the attitudes toward engineering of an intact class (N=11) of pre service and in service science and mathematics teachers. A one-group posttest only control group (N=15) was used to determine a baseline for the attitudes toward engineering (see Appendix I). The control group was an intact group of graduate students in a secondary curriculum course. The dependent variable was the attitude scale toward engineering. The treatment or independent variable for the study was the capstone course.

II.2 Subjects

The 26 subjects (see Table 1) answered a personal data sheet to determine age, gender, and level of education. Group 1 (N=11), the engineering capstone class, had eight males and three females. The average age was 31.5 with a range of 21-52. Nine of the students were science majors and two were mathematics majors. Eight of the students were seniors and three were graduates who were teaching in secondary schools. Group 2, (N=15) a graduate survey course in the secondary curriculum, had eight males and seven females. The mean age was 35.4 with a range of 25-53. All of the students were graduates and 11 were currently teaching in public secondary schools or had been before enrolling in the secondary master of education program. Four of the students were pre service teachers who had already completed student teaching. The teaching area make up of Group 2 included six science, three mathematics, two ESL, one special education, one physical education, one English teacher, and one home economics teacher.

Table 1. Personal Data of the Two Groups of Subjects (M=Male, F=Female, S=Senior, G=Graduate).

Grp	N	M	F	Mean Age	S	G	Pre Serv.	In Serv.
1	11	8	3	31.5	8	3	8	3
2	15	8	7	35.4	0	15	4	11

II.3 The Instrument

The 25-question survey (see appendix) was intended to determine how favorable students attitudes toward engineering were before and after the capstone engineering class for pre service and in service science and mathematics teachers. The survey was an attitude scale designed by the fourth author, an assessment specialist and Professor of Counseling and Educational Psychology. The survey was not piloted before this study. Ideas for questions were solicited from engineering professors, engineers working in industry and a science education professor in the Department of Curriculum and Instruction. The survey had six degrees of feeling ranging from very strongly agree (VSA) to very strongly disagree (VSD). When scored, the items were re scaled so that the higher the number between one and six, the more desirable the response. The midpoint on the scale for each item was 3.5. All 25 questions were declarative statements; e. g., question four; A problem with engineers is that engineers seldom get to do anything practical. For this question, the most desirable response was very strongly disagree (VSD) and it was rescaled as six.

II.4 Results

Answer to research question 1. The attitudes of pre service and in service science and mathematics teachers (Group 1) became more favorable toward engineering when the results of the pretest and posttest were compared (see Table 2). Means were calculated for each question. 17 of 25 questions showed increases but questions 7, 8, 17, 18, 19, 20 and 24 decreased in the posttest. A t-test for dependent data was run between means for each question, pretest vs. posttest, but none were significant, although question 12 was very close ($p = .053$). We calculated grand means, pre test means, and posttest means. The pretest grand mean was 4.50 and posttest grand mean was 4.67.

Table 2. Comparison of Group 1 Means of the Pretest and the Posttest.

Question	Pre Mean	Post Mean
1	4.55	4.73
2	4.00	4.45
3	4.00	4.36
4	5.18	5.36
5	4.45	4.82
6	4.82	5.09
7	4.18	3.91
8	3.64	3.45
9	4.36	5.00
10	5.45	5.55
11	5.09	5.18
12	4.55	5.45
13	5.00	5.36
14	4.55	5.00
15	5.00	5.36
16	3.00	3.45
17	4.64	4.27
18	4.91	4.64
19	5.00	4.91
20	4.73	5.00
21	4.09	4.27
22	4.91	4.55
23	4.73	4.73
24	4.09	4.00
25	3.64	3.82
Grand Mean	**4.5**	**4.67**

Answer to research question 2. The attitudes of secondary pre service and in service science and mathematics teachers toward engineering were more favorable than those of a convenience sample (Group 2) of other secondary pre service and in service secondary teachers? In general the sample of science and mathematics teachers indicated more favorable attitudes toward engineering than the convenience sample of 15 other teachers. Only questions 10, 11 and 12 were more favorable toward engineering in the convenience sample. The grand mean of the convenience sample, was not significantly lower than the grand mean of the engineering capstone course students.

The students in the convenience sample were also asked whether they considered themselves to be science literate and four of the 15 teachers, two males and two females, indicated that they were not science literate. Two of the teachers who said they were not science literate were science teachers but none were mathematics teachers. In

Table 3. Pretest Mean Comparison for Groups 1 and 2.

Question	Pre Mean 1	Pre Mean 2
1	4.55	3.53
2	4.00	3.86
3	4.00	3.26
4	5.18	4.40
5	4.45	4.26
6	4.82	4.06
7	4.18	3.73
8	3.64	2.86
9	4.36	4.26
10	5.45	5.60
11	5.09	5.20
12	4.55	5.00
13	5.00	4.73
14	4.55	4.46
15	5.00	4.86
16	3.00	2.86
17	4.64	4.46
18	4.91	4.40
19	5.00	4.66
20	4.73	4.66
21	4.09	3.80
22	4.91	4.33
23	4.73	4.06
24	4.09	4.00
25	3.64	3.28
Grand Mean	**4.5**	**4.15**

Grand Mean Posttest Group1 = 4.67

response to whether technology would bail us out of environmental problems, 14 of the 15 teachers said no. When asked about the main source of information about engineering and technology, the convenience sample listed television (N=3) and the web (N=3) as their main sources. Other choices were books (N=1), friends (N=2), journals (N=1) newspapers (N=2) and teachers (N=2). One student did not respond.

III. High School Science Classes

The next part of the paper addresses the pretest and posttest results of the four science classes that were taught by one of the science teachers who completed the capstone course. The following research questions are addressed: 1) Were the student posttest attitudes toward engineering more favorable than the pre test attitudes? 2) Were the posttest attitudes of the treatment group more favorable toward engineering that the posttest attitudes of the control group?

III.1 Method

A four group pretest, posttest design [2] was used to measure the attitudes toward engineering of four intact high school science classes at a local high school. Two classes were randomly selected as control groups (N=31) and two classes were randomly selected as treatment groups (N=33). The treatment group studied a three-week unit on engineering principles and design, planned by a teacher who had just completed the capstone course. The dependent variable for both groups was the 25-question attitude scale toward engineering.

III.2 Subjects

The subjects were 64 students in four classes of science inquiry in a high school (HS) of approximately 2,000 students. The control group had 17 males and 14 females. The average age was 14.4. The Treatment group had 16 males and 17 females. The average age was 14.6. Regarding the course, science inquiry, it is the minimum level science course. It is usually taken by students who do not plan on going to college or who scored low on the science placement exam and can not enroll in a higher level course in grade nine. According to the HS projections, no more that 5% of the students in these classes will go on to college. Also, only 20% of the students were making grades of B or better and 50% were failing. Their reading levels were on average at grade level except for many of the students for whom English is the second language (N=22). The social-economic level of the students was in general lower middle class to upper lower class. Only one student had a father who was an engineer and the other 63 did not know of any engineer in even the extended family.

III.3 Instrument

The instrument (see appendix) was the same one used for the capstone and baseline groups except for small changes in wording on seven questions. Those questions are identified in the appendix with an asterisk. A science inquiry class of grade nine students not involved in the study was given a graded assignment to read over the attitude scale and mark those words they did not understand. The most commonly marked words were changed based on their suggestions. For example, question 12; Engineers have little need to deal with ethical issues; was changed to; Engineers have little need to deal with questions about behavior that is morally right or wrong.

III.4 Results

Answer to research question 1. The posttest attitudes of the experimental group were significantly higher (more favorable toward engineering) than the pretest attitudes. The pretest mean (M) for the experimental group (N=33) was 3.90 and posttest mean was 4.12. A t-test for difference between the means on the pretest and posttest was significant at a probability (p) of .008. The t score was 2.822

with 32 degrees of freedom (DF). The pretest mean (M=3.72) and post test mean (M=3.69) of the control group (N=31) were not significantly differently. The t score was .268 with 30 DF and p=.188.

Answer to research question 2. The posttest attitudes of the treatment group were significantly more favorable to engineering than the control group. For the experimental group, M=4.12 and for the control group, M=3.69. The difference was significant, p=.007 with t=2.79 and DF=62. A t-test for difference between independent means on pretest scores between the experimental and control groups gave: M=3.90, SD=.54 for the Experimental Group; M=3.73, SD=.51 for the Control Group; and t (62)=1.33, p=.19.

The attitude scale also had a section for students to include some comments about their attitudes toward engineers. The pretest for both groups in general showed total ignorance of what engineers do. The posttest remarks for the control were generally unchanged whereas the post-test for the treatment groups indicated considerable knowledge of what engineers do. Two typical examples are given below (unedited).

Control Group Pretest/posttest Comments:

Pre - "I don't know a lot about them so I can't tell you."

Post -" I don't know a lot about engineers. "

Treatment Group Pretest/posttest Comments:

Pre - "I really don't know what they do so I can't say my impression." Post - "Well engineers do a lot of good things for the world and take pride in what they do. If we didn't have engineers then this world would be very crappy … but with them in the world we're OK. I wouldn't want to be one but it's good we have them in the world."

IV. Discussion and Conclusions

Currently, few secondary teachers are adequately trained to motivate and help prepare their students for careers in engineering and technology. In particular, few have any knowledge of what engineers actually do. The model presented here provides training for secondary level (grades 7-12) science and math educators that will impact the education of prospective engineers in the US. This is also needed in Nevada because the new state standards do not include enough topics in technology to promote technology literacy in high school graduates. It is hoped that such courses will increase enrollments in engineering by providing high school students with a better understanding of the profession. It may also help reduce the attrition rate of Colleges of Engineering if some of the teaching models used in the capstone course become a part of the regular engineering program. Furthermore, it should promote science literacy and improve perceptions toward technology in general, specifically toward the critical need for engineers in modern technological societies if the quality of life is to continue to improve and progress toward solving environmental problems is to be sustained.

The attitude scale provided useful information about the attitudes toward engineering of pre service and in service science and mathematics teachers as well as teachers in other disciplines. This was a pilot study and it was realized that with such small sample sizes in the capstone course (N=11) the data would be inconclusive. Examination of the pretest and posttest means clearly indicated that failure to find significance was primarily due to sample size. For example, the pretest mean on question 12 was 4.55 and the posttest mean was 5.45. This is nearly a full point increase on a scale of 1-6. However, the small sample size (N=11) so inflates the error term of the equation that it is not significant. The students in the next two capstone classes should provide data for about 40 students. That data will certainly provide a better prospect for meaningful conclusions about the impact of the capstone course in engineering.

Another critical point is that these are very high individual item means probably because intuitively one might expect people in science, mathematics and technology related careers to have more favorable attitudes toward engineers. A sample of a "normal" population that does not include so many college graduates and mathematics and science teachers would likely have been less favorable toward engineers than the baseline sample used.

The last part of the study is probably the most important. It has relevance to increasing the number of students in high school that understand what engineers do with the hope that more of them may decide to choose engineering as a career, especially those students who are intelligent but culturally disadvantaged. To put the high school study in perspective, recall how many of the students were speaking English as a second language and that nearly all of the 65 students were not college bound. They were among the lowest students academically as well as among the most socially and economically disadvantaged in a school district of over 50,000 students. Still the attitudes of students in the treatment group toward engineering significantly improved. Many of these students are not of low academic ability but they are often culturally ignorant and are simply unaware of career opportunities that are available to them, even engineering. If they were more informed, they might be more motivated to make an effort in school.

In the future we also hope to involve students in the upper level science and mathematics classes to assess their attitudes toward engineering and the effects of a unit or course in technology on those attitudes. Students in the higher group are probably more likely to be the ones who would be able to do engineering (have the mathematics and science prerequisites for college level work) if they were so motivated. We also plan to work with middle school teachers to try to motivate more students in grades 6-8 when they still have time to select the "right" science and mathematics track.

References

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Appendix: Survey of Attitudes Toward Engineering

Read each question below. Then, circle the ONE response that best expresses your attitude. Here is a key to the responses:

***VSA* - *V*ery *S*trongly *A*gree, *D* - *D*isagree, *SA* - *S*trongly *A*gree, *SD* - *S*trongly *D*isagree, *A* - *A*gree, *VSD* - *V*ery *S*trongly *D*isagree**

1. Most engineers have poor social skills.
   VSA SA A D SD VSD
2. *Engineers spend most of their time doing complex mathematical calculations.
   VSA SA A D SD VSD
3. Engineering would be a highly interesting profession for me.
   VSA SA A D SD VSD
4. A problem with engineering is that engineers seldom get to do anything practical.
   VSA SA A D SD VSD
5. *Engineers deal primarily with theory.
   VSA SA A D SD VSD
6. Engineers spend relatively little time dealing with other people.
   VSA SA A D SD VSD
7. Engineers spend most of their time working in offices.
   VSA SA A D SD VSD
8. Engineers spend most of their time working with computers.
   VSA SA A D SD VSD
9. Engineers seldom get involved in business decisions.
   VSA SA A D SD VSD
10. Engineers have little need for knowledge about environmental issues.
    VSA SA A D SD VSD
11. Engineers have little need for knowledge about economics.
    VSA SA A D SD VSD
12. *Engineers have little need to deal with questions about behavior that is morally right or wrong.
    VSA SA A D SD VSD
13. Engineers have little need for knowledge about political matters.
    VSA SA A D SD VSD
14. To be a good engineer requires an IQ in the genius range.
    VSA SA A D SD VSD
15. Engineering is a poor career choice because job availability is so dependent on defense spending.
    VSA SA A D SD VSD
16. *Engineers need a great deal of inborn aptitude for science and mathematics.
    VSA SA A D SD VSD
17. Most engineers have very narrow outside interests.
    VSA SA A D SD VSD
18. Engineering is important to future U.S. economic success in the world.
    VSA SA A D SD VSD
19. *Engineers typically have very little common sense.
    VSA SA A D SD VSD
20. A career in engineering would be financially rewarding.
    VSA SA A D SD VSD
21. Most of the skills learned in engineering would be useful in everyday life.
    VSA SA A D SD VSD
22. *Engineers are not typically people who are fun to be around.
    VSA SA A D SD VSD
23. *Engineers do not tend to be appreciative or the arts.
    VSA SA A D SD VSD
24. Engineers are frequently those individuals who were regarded as "nerds" in high school.
    VSA SA A D SD VSD
25. If I had it to do over again, I would consider a career in engineering.
    VSA SA A D SD VSD