Problem Solving and Creativity Experiences for Freshman Engineers

Karen A. High, Cynthia Mann, Ben Lawrence
School of Chemical Engineering
Oklahoma State University
Stillwater, OK 74078

Abstract

An engineering orientation class at Oklahoma State University has provided an opportunity to develop and enhance problem solving and creativity skills for freshman. For two semesters, classes have been led through experiences that include making candy airplanes, making better pizzas, and devising ways to keep ice cream from melting. These three projects have served as a vehicle for introducing students to the important tasks involved with engineering product and process design. This course is also part of a larger effort towards introducing students to entrepreneurship concepts.

During the multi-week design project portion of the course, students are given a vaguely worded open-ended market-driven design problem, and asked to find a solution. The problem is based around food, such as pizza or ice cream, and is designed to be fun. Group dynamics, project planning, problem definition, brainstorming, experiment design, and creativity are some of the major points discussed. The project culminates with the student presenting their solutions to their peers and demonstrating any prototypes they developed.

Introduction

College students typically do not see engineering as a creative field of study. Students see engineering as very mathematical and rigorous. Freshmen often look at the daunting curriculum and see an abundance of work with little or no reward. What is not apparent in the underclass-engineering curriculum is the amount of creativity that is necessary to solve industrial problems[1]. This becomes more apparent in advanced courses, such as senior design, but we must be able to retain students until that level. Additionally students feel that they will be attacking projects on an individual basis, as was the case for much of their high school experience. Once the students reach later classes, they realize that the norm is to solve problems in student teams.

Students retained until graduation sometimes also express apathy toward the field of engineering. Upon finally reaching graduation, some are so burned-out that they are not able to look forward to beginning a new career. At OSU some were specifically asking for more opportunity to have creative input in their education. It was believed that if they could take more ownership in their projects—by expressing their unique ideas, that they would feel more pride in their work[2]. Thus projects that had been exhausting because of their abstractness might become less exhausting because of the personal pride and motivation of working toward one's own creative expression[3].

Additionally, industrial employers seek innovative solutions to their problems and new engineers should be practiced in creative exploration of problems at hand. It is unrealistic to expect a student who has never solved a problem that did not come packaged with all the necessary information to adjust easily to the "real world" where information is almost never readily available in its most useful form. This brought about the birth of this research into adding more creativity to engineering education. Knowing the goals and benefits of increased creativity, the questions of how, when and where to implement it still remained.

Looking at upper class courses, they are full of complex technical ideas. However, lab courses and projects do offer the opportunity to use creativity. Why then do students feel stifled? In most cases students are afraid to go out on a creative limb—grades are a driving force for most student effort. Nobody wants to put his or her grade in jeopardy just to view an assignment from an alternate perspective. The stereotypical learning environment is highly structured, not supportive of unique ideas about how to do things. This is often because the more alike a group of students is; the easier it is to teach them. The "read and regurgitate" style of the first 12 to 14 years of education infuses the idea that all that the professor wants students to know is what the professor has already said. However, this will not be an acceptable mode of thought in practice. Students must learn that independent thought and creative problem solving are valuable skills. This is accomplished by providing a learning environment that supports these traits.

Underclass courses then are preferable because the earlier that creative problem solving is taught, the more use a student may make of it. However, these classes offer different challenges. Though the technical content of an under-class course may be lighter, one is also dealing with less mature individuals. It is also in these courses that the "basics" are being taught. Therefore, if students do not yet understand the basics, how can they possibly apply these concepts to creative problem solving?

The solution was to teach the complete problem solving process using non-technical problems. Non-technical problems are also preferable because expertise is a prerequisite for creativity.[4] It is unrealistic to expect someone to be creative in an unfamiliar situation. The pilot study implementing these exercises was in one section of the ENGR 1111, a freshman orientation course, in the Fall 2002 and 2003 semesters.

Background

First semester freshmen and transfer students are required to take an orientation class at most universities. At OSU, this is a one credit hour course which has major objectives of introducing students to the different engineering disciplines as well as familiarizing them with the campus and college life (library/counseling/career services, computer labs, study skills etc.). In order to meet certain ABET criteria, the College of Engineering requires certain activities to be accomplished in all ENGR 1111 sections. A list of these requirements, as well as a few other common exercises done in the average ENGR 1111 course is shown in Table 1. Creative problem solving techniques and a design project were added to the curriculum of one section of this orientation course having 20 enrolled students for Fall 2002 and 2003 semesters.

Table 1. Required and Common Activities for ENGR 1111.

At least one team activity. (ABET outcome d)
At least one activity involving ethics. (ABET outcome f)
At least one oral presentation. (ABET outcome g)
Library training and assignment. (ABET outcome l)
Requirement to attend a professional society meeting or career fair. (ABET outcome l)
At least one activity involving contemporary issues. (ABET outcome j)
Show competency in MS Word, Excel, and PowerPoint. (ABET outcome k)
Awareness of OSU Computer Services. (ABET outcome k)
Additional activities common in ENGR 1111
Academic Success / Study Skills / Time Management
Personality typing using the Myer's Briggs Type Indicator
Career Services Awareness / Resume Writing / Interviewing Strategies
Planning of class schedules or a four-year Study Plan

In both the semesters (Fall 2002 and Fall 2003), Dr. High taught sections of Engineering 1111 that included problem solving and projects. Chemical engineering faculty also taught other sections of 1111.

Approach

The course is taught for 1 hour each week during a 15 week semester. The concepts of problem solving, creativity, and product/process design were introduced using several weeks of the course. The mode of teaching has been through directed activities to teach students the concepts. The majority of the creativity exercises included teaching a problem solving process through the use of the Pizza Project for the Fall of 2002 and an Ice Cream Project for the Fall of 2003. However, the students also completed several other exercises. Recalling that there were already a significant number of objectives that must be completed in the course, many of the traditional activities were integrated into project related activities. A complete list of creative activities is given in Table 2. More detail is given in the following sections.

Table 2. Exercises for Problem Solving and Creativity

Product/Process Design: The candy airplane.
Myers Briggs Type Indicator and Project Group Dynamics
Problem Definition: What is the Problem?
Brainstorming: How can we solve the Problem?
Experimental Design: How will we know if our solution is good?
In Class Experiments for the Problem
Presentations

Candy Airplane

The first group creative activity was to use a bag of assorted candy (gum, Tootsie Rolls, Lifesavers, etc.) and small office supplies (notepad, rubber bands etc.) to construct an airplane (based on appearance only). After creating a prototype, the groups were instructed to manufacture as many additional airplanes as they could in a specified time. During production time, the instructors simulated process upsets that the groups had to overcome (for example loss of raw materials, cutbacks in the workforce, employee injury etc.). The students employed great creativity, not only in the airplane designs, but also in working around the processing calamities. This activity led to a discussion of the manufacturing process and product design, and it was also a lot of fun! After this experience, the students understood that this was not going to be a "normal" class. They also began to realize that this was an atmosphere where positive feedback was readily available for unique responses.

Multi Week Projects

Problem Solving

With problem statements in hand, and groups of four, students were sent to incubate on a problem until the next week when they began a guided journey through the problem solving process. *Strategies for Creative Problem Solving*[5] was used extensively to craft the classes' exercises in each step of the process. As we called them, the steps were (1) Problem Definition, (2) Brainstorming Solutions, (3) Deciding a Course of Action, (4) Implementing the Solution (experimentally), and (5) Evaluating the Solution. Each step involved an in-class group activity and a group homework assignment; many also had an individual assignment unrelated to the Pizza or Ice Cream Project.

Pizza Project

The first day of class, each student was given a notebook to serve as a journal and a laboratory notebook for the project. Throughout the semester they were instructed to use the journal to complete some assignments, keep track of project related information (and data), and also provide feedback about class activities through journal entries. This was found to be an effective method of illustrating the importance of laboratory notebooks—a concept foreign to many engineering students. The success of this project relied on the students' comfort in interacting with the instructors; the notebooks seem to be a non-threatening forum for feedback.

The last 12 weeks of the semester integrated the Pizza Project into the class activities. They were placed in teams of four and given a scenario in which they were all design teams working for a company that had been contracted by Fred's Pizza. Unlike design problems that request a course of action given a well-defined problem, the students were instead given a symptom to alleviate:

> Customers of Fred's Pizza are calling in to complain that delivery pizzas are arriving cold, and that grease is leaking through the boxes and staining tablecloths.

This open ended statement was developed to reflect the nature of industrial problems. Unlike textbook exercises, in industry, we are not given all of the constants, variables, and conditions in a package. Instead, most industrial problems are only realized when the symptoms become apparent, it is then the job of the engineer to determine what real problem is causing the symptoms: exactly the type of creative experience that is rare to undergraduate education.

One major challenge was implementing an entire project in a one credit hour course without overloading the students. It was desirable to give group time during class, and not require extensive group meetings outside of class. Therefore many class periods were spent half disseminating information through lecture and half in group work. This forced the generation of several handouts to explain complex strategies in problem definition, brainstorming, etc. Hopefully, the students will find those resources useful in the future.

Throughout the project, students were encouraged to "research" the causes and effects of the symptom by directing questions to the instructors. In order to make decisions about how to solve the problem (alleviate the symptom), they needed more information. Information was only available on request, therefore, depending on the questions the students asked, each group had different information on which to base their recommendations for improvement. Of course, when similar questions were asked, the groups received the same response to keep the information consistent. This method of providing information can be time consuming, but like an industrial problem, it was important to reward effort with a better understanding of the situation at hand.

A conscious effort was made to not steer the groups in the same direction. Diverse solutions were encouraged, and ideas about changing the pizza recipe and delivery methods were a portion of the final recommendations made by the class. However, in an effort to allow the opportunity to see a solution at work, students were given one class period to perform experiments on their solution to the problem—as they had defined it. This resulted in each group designing, or redesigning, a pizza box.

The choice of testing a pizza box was not made by the instructors, it simply happened to be common to every group. Students were given only two stipulations: (1) requests for materials to use in experimentation were supplied to the instructors one week prior, and (2) company policy discouraged the use of actual pizza in the laboratory (due to safety considerations), thus pizzas had to be simulated by other means. Both of these stipulations proved to be excellent learning tools.

Each group had a conference with the instructors outside of class during the week prior to performing their experiments, in order to go over their (informal) experimental plan. They had all decided on a unique way of simulating a pizza (from Hot Pockets to bags of rice, or slices of bread) and had requested ample raw materials to do the tests they were interested in. In this sense it appeared that they had carefully planned their experiments. However, only one of five groups remembered to ask for simple experimental tools such as thermometers, stopwatches, measuring cups and a source of heat. In keeping with the general theme of the project, no information or resources were provided without a specific request, this was in effort to simulate a real work environment and the responsibility of an engineer. One cannot expect to walk into the laboratory and find a convenient supply of chemicals and equipment if one did not first order those materials. The instructors used the conference time to allow groups to request experimental tools in addition to the ones previously requested. Everybody had all the supplies they needed on the day of experiments.

The week following the in-class experiments, students brought in prototype solutions, and the instructors provided real pizza for testing. Additionally, several individuals from the department were asked to attend and judge the solutions. Each group gave a presentation (using PowerPoint) that included their unique problem definition, and they ways they had considered solving it. Each group also included data from their experiments (graphed in Excel) and discussed how it supported their final decisions.

The level of student maturity and achievement on this project astonished the instructors. With no instruction in the area of effective presentation planning, all groups presented well-organized and professional presentations. Many of the written assignments also exhibited an impressive mastery of computer software and organization. These students rose to the challenge put to them and truly performed far beyond the instructors' expectations.

Ice Cream Project

The following is the assignment given for the ice cream project in the Fall of 2003.

> Betty's grocery store has hired your engineering firm to research the problems underlying some customer complaints. They have been receiving frequent phone calls from angry customers complaining that the Ice Cream Brand XYZ that they have bought from the store is melting by the time it reaches home. The firm has decided to assign several teams the task of determining the best method of improving this situation. Each team will present its solution to the Board of Directors on November 13. The team with the best ideas (as determined by the Board) will receive a merit bonus.
>
> Company policy requires regular updates on all developing projects, the timeline below lists dates for all necessary reports. Also listed are company resources available to you. You will also need to set up two times to meet with your supervisor (Karen High) outside of class as a group to discuss project progress. An email sent to Karen 2 days ahead of the meeting is required to set it up.

Table 3. Assignment Schedule for the Ice Cream Project

Date	Useful Resources	Item Due
9/18	Company Seminar on Effective Project Planning and Project Definition	
9/25		Project Plan
10/2	**Group Document Workshop**	Problem Definition
10/9	**Company Seminar on Brainstorming Techniques**	
10/16		Brainstormed Solutions
10/23		
10/30	Company Seminar on Experimental Design Considerations and Company Resources	Supply List for Experiments
11/6	The company laboratory (514 EN) will be available for you to test prototypes 3:30-4:20. Provide management with a list of supplies one week prior.	Experimental Design
11/14	Use MS Excel to represent your findings. Use MS PowerPoint to create slides. You will need to make transparencies to use the overhead projector in 514 EN.	Experimental Results Project Presentation

Because we have several teams working on solutions for Betty's Groceries, it is best to direct inquiries through management. Management will also be available to assist in providing company resources necessary for your project.

Assessment

Several different types of assessments have been done on the ENGR 1111 creativity courses. These include:

Personality typing
Retention information
Course evaluations and student comments
Pizza/ice cream project surveys

Personality Typing

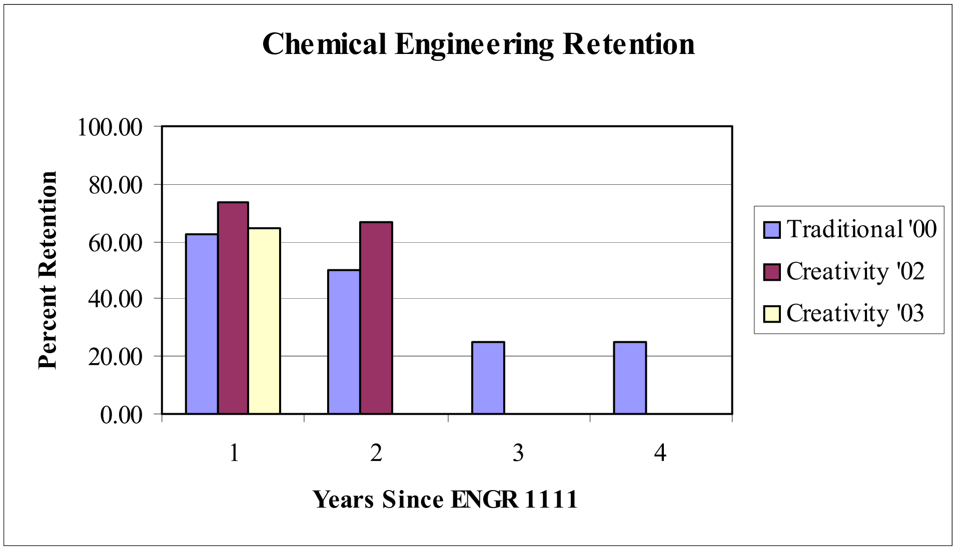
An interesting thing happened involving the personality typing the class completed in Fall 2002. While personality types are often an excellent way to glean insight on personal preferences and strengths, when we actually applied this knowledge to the teams for the Pizza Project, the information became more meaningful to the students. Additionally, discovering the class personality type distribution gave insight to understanding the class' apparent enthusiasm for the course. Only two of twenty students were introverts, thus the highly interactive nature of the entire course was a positive learning environment for the class as a whole[6]. This personality distribution was very different from the other sections. For the Fall 2003 class, 13 out of 20 were extroverts in the Myers-Briggs personality indicator.

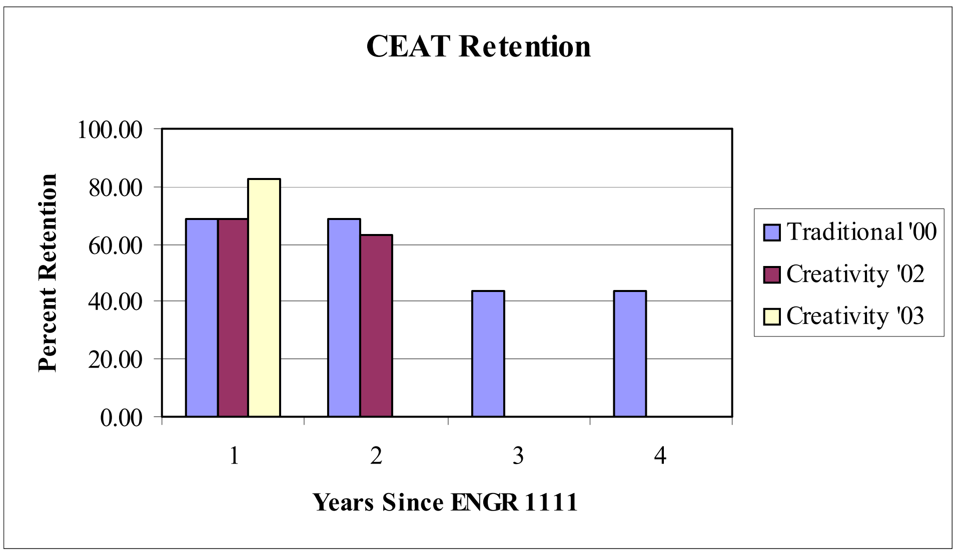
Retention Information

Presented in Figures 1 and 2 are retention percentages determined for various ENGR 1111 sections. These sections are considered chemical engineering sections because a CHE is the major with the highest number of students starting out in the course. The professors that teach the course are chemical engineering faculty. The initial numbers of chemical engineering students are listed here:

Traditional '00 (16/18)
Creativity '02 (15/21)
Creativity '03 (17/20)
CHE1 '02 (9/21)
CHE2 '02 (14/21)

In the "Traditional '00" class, the students of Fall 2000 completed assignments to fulfill the objectives covered in Table 1. These activities were not related to one class project. CHE1 and CHE2 were taught by other CHE professors in the Fall of '02, again covering the same activities listed in Table 1. The professor for CHE1 typically introduces the students to chemical engineering curriculum and concepts while the CHE2 professor tends to focus on study and





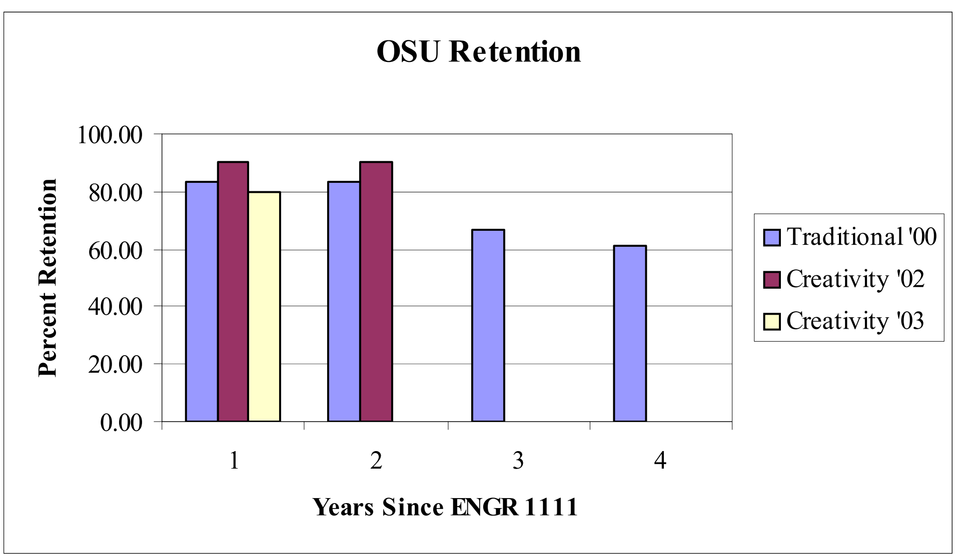
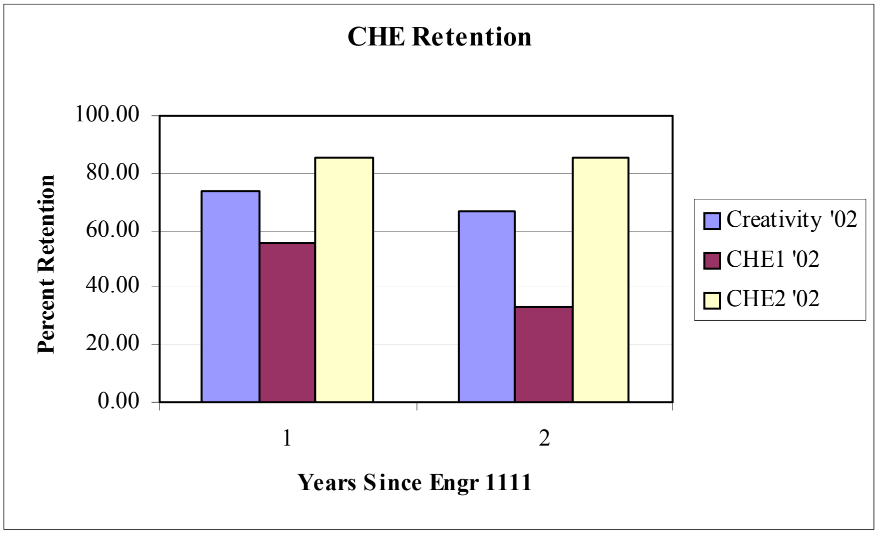
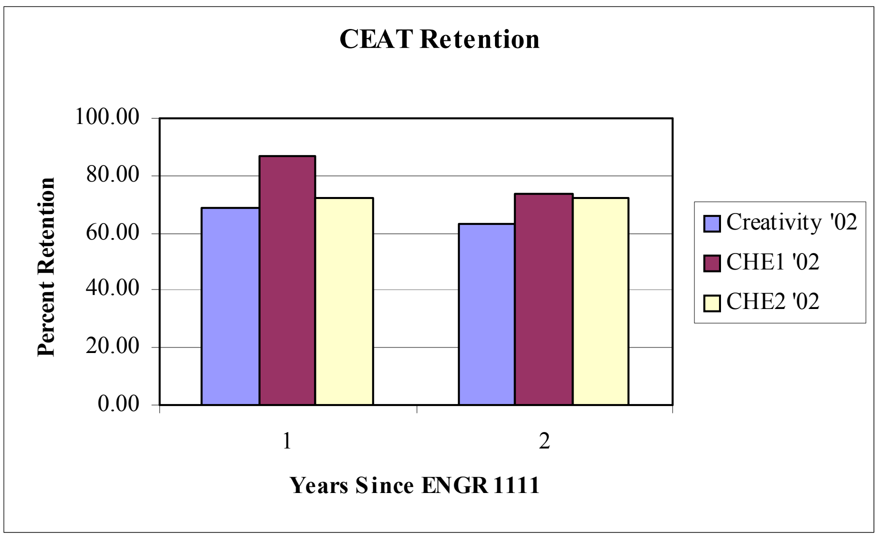


Figure 1. Retention Information for Dr. K. A. High ENGR 1111 Sections





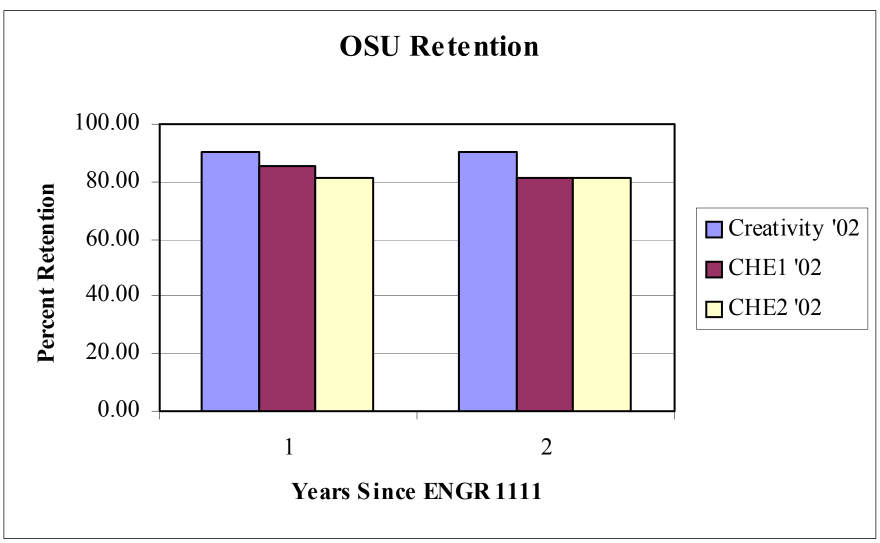


Figure 2. Retention Information for Various Fall 2002 ENGR 1111 Sections

student survival skills and college orientation.. Creativity '02 and '03 refer to the two semesters that Dr. High focused on the group projects.

In looking at the data for Figure 1, it appears that for '02 and '03 the retention in CHE in those two semesters are at or above the level for the traditional approach. Students in the Fall '02 class appear to have better retention in the CHE major. Dr. High taught all three sections. Retention of students in the majors of the College of Engineering, Architecture and Technology were at the same level as well. OSU retention was roughly the same for all three semesters as well.

Figure 2 shows some interesting information. CHE retention for the creativity class was higher than one of the traditional CHE classes of Fall '02, and not the other. CEAT retention was higher for the traditional CHE classes and OSU retention was higher for the creativity class. Of course it is important to note that these results reflect the statistics of small numbers and larger data sets are required for conclusive information.

OSU statistics show that overall (for all OSU students), for freshman that started in Fall of 2000, 81.7 percent were retained to their sophomore year, 71.1% to their junior year, and 65.8% to their senior year. For Fall 2002 freshman, 80.4 became sophomores at OSU (in 2003), and 71.2 became juniors in 2004. For Fall 2003, 78.1% became sophomores at OSU in 2004. Information on CEAT retention shows that of the 734 freshman that started out in Fall 2003, 61.2% became sophomores in CEAT.

Course Evaluations and Student Comments

To gain additional insight as to effectiveness of the course, course evaluation numbers were evaluated. These are the evaluations that OSU has the students fill out for every course. In the first column is the Instructor number (maximum is 4.00) and the second column is the Course number.

	Instructor	Course
1997	3.65	3.35
1998	3.41	3.18
1999	3.83	3.60
2000	3.41	2.93
2002	3.32	2.74
2003	3.81	3.44
Ave	**3.57**	**3.21**

It is interesting to note that the semester where creativity was first addressed, Fall '02 has the lowest Course rating (2.74), but in Figure 1 showed a high retention in CHE. Conversely, the semester of Fall '03 where there was a lower retention in CHE had the highest Course (3.44) rating and second highest Instructor (3.81) rating. It appears from the middle panel of Figure 1 that many of the Fall '03 students stayed in CEAT. The focus in the creativity sections was on engineering concepts and only a minor amount of time was spent discussing specifics of Chemical Engineering. The cause and effect of these results need to be the focus of further study.

Student Comments in 2000

The following comments were provided on the Instructor/Course evaluations that are tabulated above. “Team building would have been fun.” “Fun class and friendly professor.” “Between adjusting to college and difficult courses, I really needed this class.” “Work load too much, I did more in this class than in CHEM 1314.” “I wish I learned more about CHE, I don’t even know if that’s what I want to do anymore.” “Feeling negative towards major in CHE.” “The road ahead isn’t pretty.” “Busy work assigned in the course.” “I think more should be done from a book or research more to gain more information about Chemical Engineering.”

Student Comments in 2002/2003

The following are comments from the university evaluation for the two semester that the creativity experiences were tried. “More info in class rather than on-line.” “Try to explain briefly the different fields of engineering.” “Dr. High has great enthusiasm.” “Candy….Yum.” “I enjoyed it very much” “Course was fun.” “More classes on MWF with more time, more credit hours.” “This course taught me a lot about what it takes to be an engineer.” As can be seen, these comments are more positive in nature than during Fall 2000.

Pizza/Ice Cream Project Surveys

The students in both sections (’02 and ’03) were given an opportunity to fill in an open ended survey. For the Pizza Project, there were comments such as “Don’t have us do work outside of class.” “Wish we could have gone to the computer lab more often.” “The problem I had was that I was told to be creative and not let our design stand in our way, but in the end we had to make our design. So we were extremely limited on what we could do.” “I didn’t like the competition between groups.” “I found it difficult to be creative with so many restrictions.” “I did not like the presentation part because I still have trouble speaking publicly.” Positive comments included “All the pizza things were great. Add eating more pizza.” “I learned more about what engineers do while on a project and how they do their job.” “It really did enhance my creativity.” It helped me understand what engineering is about.” “I enjoyed the brainstorming, that was fun.” “I used to hate group things, but this make it a little better.” “My favorite part was testing our experiment design.” “The pizza project told me the importance of cooperating and when we cooperate, ideas occurred on after the other.”

As part of the Ice Cream project survey, the students were asked “Are you more informed about problem solving strategies based on information obtained in this class?” The class results were 14 yes, 1 somewhat and 1 no. Comments on this question were “I have learned the steps of how to go about solving a problem.” “I learned that are many sometimes trivial yet imperative steps to problem solving.” “I felt like we were giving technical names to a logical thought process.” “Iteration is an excellent method of comprehension/learning.” “The ice cream project really helped us apply the strategies.”

The next question was “Are you now more comfortable working in groups based on experiences in this class?” The results were 12 yes and 4 no. Comments on this question included “Was already a proficient team/group member." I needed to learn how to work in college groups because it is more difficult." "I feel that this has taught me that working in groups is truly the way to go to get work done." "I had to deal with organizing and preparing group projects for this class." "I have worked in groups before but I have seldom been the leader, this gave me a chance to lead. The people that I worked with are different than I normally work with so it gave me different perspectives." "Usually group assignments are done in a more strict/uptight environment. The group assignments in this class were fun and inventive. This results in more relaxed group members." "Needing time to work outside of class was new."

Future Directions for Assessment

We plan to continue to assess the students from Fall '02 and Fall '03. A survey is being developed that will be administered to all CHE Students (Sophomore, Junior, Senior) to determine the benefits of various ENGR 1111 sections, Creativity, Traditional Chemical Engineering, Women in Engineering, Multicultural, and Scholars/Honors section.

In proposing future studies for Fall of 2005 and beyond, the method of assessment will need to include a more accurate measure of ability and rely less on student attitudes. It was impossible to tell whether students' creativity was enhanced and whether retention will be improved. However, the students were noticeably more active in class discussion as compared to previous classes. Some students are still corresponding with the instructor after the completion of the two semesters; this is a positive and unusual occurrence. In fact, one student is developing patents based on several of her creative ideas. Future studies will also be longitudinal in nature so effects of creativity on retention rate may be measured.

Conclusions

Student feedback at the end of the course was generally positive for both semesters. Though a few students did not see value in the project, all admitted that the project had been enjoyable. Some students were frustrated that they were asked to be creative and then given limitations within which they had to work. Comments like "I still wonder if engineers in the real world use project plans" indicated a negative perspective on the project. However, from the instructor's perspective, the negative responses support the need of this type of project more than the positive ones. All of the activities in this project will be encountered in future classes as well as engineering careers.

A major unexpected benefit of adding the project was the continuity it added to the course. This also added more work for the instructor, however. All freshmen are required to complete certain library and Internet exercises, and also use Microsoft Word, Excel, and PowerPoint. It is much easier to use weekly assignments that are independent of each other. However, the effort was definitely worth it and made the tools realistically useful for the students. In retrospect, this project may have had a more positive influence on helping freshmen understand the role of an engineer, than it was an opportunity to express creativity. In either case, the improvement of classroom atmosphere and continuity of assignments that it brought were worth repeating.

The College of Engineering, Architecture and Technology is in the early stages of developing and Entrepreneurship Program. This as well as other efforts to improve the curriculum for early Engineering Students will rely on several of the ideas presented in the described ENGR 1111 course. Focus will be expanded on product and process innovation, business skills, brainstorming, project planning and management, creativity, problem solving, intellectual property, and a capstone entrepreneurship project.

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Author Biographies

KAREN HIGH earned her B.S. from the University of Michigan in 1985 and her M.S. in 1988 and Ph.D. in 1991 from the Pennsylvania State University. Dr. High is an Associate Professor in the School of Chemical Engineering at Oklahoma State University where she has been since 1991. Her main interests are Environmental Process Design, Industrial Catalysis, and Creativity in Engineering Education.

CYNTHIA MANN obtained a B.S. degree in Chemical Engineering from Oklahoma State University in May 2003. This is her second publication and she is looking forward to a career of many more. Cynthia's future educational plans include graduate studies in biomaterials and tissue engineering.

BEN LAWRENCE obtained a B.S. degree in Chemical Engineering from Oklahoma State University in May 2004. This is his first publication and Ben's future educational plans include graduate studies in chemical engineering.