Use of Concept Development Projects in Science and Engineering Courses

Adrienne R. Minerick[1]*, Giselle Thibaudeau*[2]

Abstract – During their collegiate careers, students usually learn more than the facts and theories they gain from text book learning and note taking in class. However, the skills which serve them best and prepare them to be productive, technical, members of society include problem solving skills, information filtering skills, and logic skills. Unfortunately, the traditional classroom does not focus on these skills nor does it usually provide individual practice linking unique concepts together. This paper and the corresponding presentation will discuss a concerted effort to strategically develop these skills in Science and Engineering students through Concept Development Projects associated with core or elective courses in the respective curriculum. Two main Concept Development Project efforts at Mississippi State University will be discussed. G. Thibaudeau taught a complimentary section of Honors Cell Biology that enrolled 5 to 15 undergraduate students of the 180 total students enrolled in the parent Cell Biology class each semester. A. Minerick taught an Analytical Microdevice Technology elective course in chemical engineering enrolling 5 graduate students and 10 undergraduate students. Both courses included an independent cooperative learning project structured to allow students to develop a researchable concept via independent reading, discussion, and mini-lectures. This effort has evolved with each implementation in order to address shortcomings noted either by students or professors. Success implementing these skills in students has varied by student, but the skill set demonstrated overall by each class has increased with each implementation.

It has become apparent that engagement of students in critical thinking and research increases student awareness of and excitement for science and engineering and the likelihood of retention through bachelor degree programs and therefore the likelihood of matriculation into graduate programs [Prince, 8,9]. The goal of this manuscript will be to provide a guide for development and implementation of Concept Development Projects as well as resources to assess student skills. The information will be presented so that faculty in diverse fields of science and engineering can translate the concept to the classroom and foster development of problem solving, information filtering, logic, and concept linkage skills in their students.

Keywords: concept development, problem-based learning, engagement

INTRODUCTION

Although the need to increase interest, participation, recruitment and retention in the sciences and engineering at all educational levels is a true national concern, evidence suggests that many students who have aptitude/interest in these areas become disillusioned with their college-level studies and opt for non-science and non-engineering majors. In an attempt to find solutions to this problem and the loss of intellectual capital, high schools, colleges, and universities are gradually reexamining, restructuring, and increasing their approaches to the recruitment, training, and retention of students in science and engineering fields [NRC, 4,5; NSF, 6].

There has been a tremendous growth in technology development and use and the corresponding need for problem-solving skills and inquiry based learning. Although the use of technology and the application of inquiry based teaching in the classroom has certainly increased in the college classroom during recent years, the traditional problem solving conducted in the classroom has the teacher posing a well thought out problem for the students to approach in a fashion that has been demonstrated by the professor in lectures or in examples. That is, significant background work has already gone into the problem to determine if it is feasible, what tools will be needed to solve the problem, and that the necessary information is readily available for the students. However, once these students enter the workforce or graduate school, they are unlikely to encounter tasks of this nature. If a supervisor has gone to the trouble to define a problem with that level of precision, that supervisor has nearly completed the task and wouldn't be handing it to someone else to complete. This suggests a disconnect between the skills students desperately need to learn and what skills (or lack of skills) these students are acquiring in the classroom.

Many proponents have advanced problem-based learning as a technique for students to learn to locate resources and teach themselves and each other concepts in the process of solving a central problem. A central hypothesis driving several efforts undertaken by the authors is that engagement of students in research and inquiry early in their college career not only helps to connect students' acquired skill set with the skill set needed to enter the workforce and/or to pursue graduate degrees but also increases interest, awareness and excitement in science and engineering, the likelihood of retention through bachelor degree programs and ultimately enhance the likelihood of matriculation into graduate degree programs or careers in science and engineering. In this work, we describe our efforts to advance the problem-based learning approach further such that students engage in the experience of starting with a broadly defined idea, seeking information to limit that idea into a well-defined problem and then proposing a viable strategy to approach that problem. Full completion of the problem is not considered in this manuscript, as the specific topics discussed are both at the leading edge of individual research fields.

In this paper, the need for, concepts of, and approaches to problem-based learning and teamwork in the undergraduate science and engineering classrooms will be discussed briefly. In any such strategy, team dynamics are essential to student, professor, and project success. Minerick and Thibaudeau have taken an approach representing a merger of problem-based learning techniques in an effort to enhance student skills in the sciences and engineering while advancing individual research productivity. A discussion of the goals of these Concept Development Projects is followed by course descriptions for the Cell Biology and the Analytical Microdevice Technology courses within which these projects were implemented. General conclusions and advice are provided for others considering adopting this Concept Development Project approach.

Semester long projects have become fairly common in upper level engineering courses and capstone science courses, more commonly in programs with relatively small enrollments. This form of experiential learning has proven the optimal format for teaching students to approach larger tasks, to work in teams, and to adopt communication and soft skills required of accreditation groups (e.g. ABET (write out), the workforce, and any graduate program. The literature on this is quite extensive in both engineering and biology.

Many sources speak to the interrelatedness of research and education and the need to engage all students in research and discovery-based learning. The NSF and NRC urge that "students have access to supportive, excellent undergraduate education and that all students learn these subjects by direct experience with the methods and processes of inquiry" [NRC, 4,5; NSF, 6]. The need to employ research as a pedagogical tool in undergraduate education is also the cornerstone of several publications and innovative programs that have been successful at training students to formulate hypotheses and perform original research at the undergraduate and graduate level [Prince, 8,9; NSF, 6; Wankat, 12]. These students in turn become contributing members of the workforce, primary candidates for excellent graduate programs, and represent the nation's future scientists/engineers.

Unfortunately, during the first two years of an undergraduate degree, a student's only exposure to research, if at all, is through the undergraduate curriculum, which in its traditional form tends to discourage collaborative learning and/or teamwork. Studies suggest that this environment discourages students from pursuing advanced degrees in science and engineering and creates a disproportionate hardship for students from underrepresented and at-risk groups [Seymour, 10]. Any program, which aims to increase student recruitment and retention in the sciences and engineering fields, should provide an environment for students to experience the collaborative nature of science and engineering. Such an environment also encourages students to pursue careers and/or graduate degrees in these areas. No matter what the approach, undergraduates learn best about research and careers in science and engineering by being part of a team, interacting with other scientists and engineers, and by engaging in real research.

THE IDEA

This type of open ended, evolving concept development project has been implemented by the authors in the undergraduate classroom. Thibaudeau recognizes the tremendous benefits to and growth in undergraduate students involved in research experiences and over the past few years has moved faculty-guided research experiences for individual undergraduate students in her research lab to groups of students from the classroom to the lab. Thibaudeau began this concept development approach in a Cell Biology course within which a subset of students enrolled for Honors credit. Thibaudeau set this group of 12 students on inquiry based search for examples of engineered materials or processes that were inspired by nature (ie. Bio-Inspired Designs). After some background training, the students began searching for information independently and settled into an approach that would contribute to developing a sample biologically inspired material. The group collectively came to a consensus on what was the most viable pathway forward. Much of the progress in this group was conducted via interactive discussion sessions where summaries of the next steps were the output of each meeting. Minerick adopted a similar approach in the Analytical Microdevice Technology Course, which she taught as part of her NSF CAREER award (2008). The outputs from this course were structured such that each student team completed a manuscript formatted for journal publication by the end of the semester. The authors also plan to employ a similar multidimensional learning tool known as the Jigsaw Method [Aronson, 1; Johnson, 2; Smith, 11] to develop REU Jigsaw Group Challenges should their pending NSF REU site: Breadth and Depth Materials Research be funded. The format for this type of concept development project is outlined below.

Concept Development Project in an Honors Core Biological Sciences Course:

This concept development project idea began during the 2007/2008 academic year as an approach to meet the requests of a subset of students enrolled in Cell Biology 2103 and wishing to be involved in an "activity" outside of the classroom. Recognizing the mutual benefit of engaging the curious minds of talented undergraduate students, Thibaudeau has encouraged and implemented inquiry based learning and research in the lab as well as the undergraduate classroom. Having students involved in the research lab for academic credit, directed individual study, or wages is not uncommon and Thibaudeau historically has had several biological science majors involved in her lab each semester. Faculty-guided research experiences for individual undergraduate students has gradually moved to faculty and near peer mentor-guided research experiences for teams of students from the classroom to the lab. After discussing the need for any plan of action to be mutually beneficial for the students and the professor, both who have limited available time, this relatively informal concept development project approach was conceived. Thibaudeau set the original group of 12 students from Cell Biology on an inquiry based search for examples of engineered materials or processes that were inspired by nature (ie. Bio-Inspired Designs). After some background training, the students began searching for information independently and settled into an approach that would contribute to developing a sample biologically inspired material. The group collectively came to a consensus on what was the most viable pathway forward. Much of the progress in the original group as well as in the subsequent group has been conducted via interactive discussion sessions, where summaries of the next steps are the output of each meeting. Interestingly, each group has been represented by biological science majors as well as by biological engineering majors. The knowledge base of and the approach taken by each group of students has been beneficial to the students, the faculty mentor, and the project. Several students that have been part of Thibaudeau's research lab have taken lead roles in leading and near-peer mentoring of the development concept project teams. Likewise, several students that participated in the original Honors group now serve as near-peer mentors and student leaders greatly respected and appreciated by the concept development project student teams. Undergraduate students typically have limited time to devote to any project or activity that is considered to be outside of their required curriculum. However, Thibaudeau has found that when students become part of a bigger research project and develop to a point that they have ownership in the ideas, progress, and success of the research, they will devote the necessary time to see the project through. Simply put, students buy into this type of concept development project because of the excitement generated and the sense of ownership gained.

Very few freshman/sophomore level undergraduate students have a working understanding of research and even fewer know where to begin to ask the relevant questions. In the concept development approach discussed here, the larger research focus of the lab is discussed, and this is followed by a discussion of smaller relevant projects, related to the larger research focus and needing attention. The specific focus of the particular concept development group project is then decided on by the group. Milestones to be met throughout the semester (or year) are given to the students and are designed to build on each other, employ teamwork growth and success, empower the individual as well as the team, and result in a final oral presentation and ultimately an article for journal publication.

Analytical Microdevice Technology Elective Course:

A more formal course example of the concept development project exists in Minerick's Analytical Microdevice Technology course. This chemical engineering course had four learning activities that included lectures, a game day modeled after Survivor Classroom [Newell, 7], an article discussion day, and a semester-long concept development project. These activities complimented each other to provide the students the fundamental knowledge, practice applying that knowledge, and discussion of applications of that knowledge. Lectures typically covered the fundamental knowledge needed to understand micro and nanoscale forces in microdevices. The Survivor game provided practice working smaller design exercises, practice with calculations, and knowledge reinforcement. The weekly article discussions provided an opportunity for students to link their fundamental knowledge to the cutting-edge, new micro and nanotechnologies reported in the literature.

The primary class activity which provided in depth training in logic and information filtering skills was the semester-long concept development project. The students were provided early in the semester an overview of the large, open-ended, concept development project that they worked on in four person teams. The students were given the latitude to choose their own specific topic provided that it focused on any small-scale technology that would address an important biomedical application (diagnostic or other). Their novel concept was to link together or build from existing theoretical and experimental reported technologies in the realm of chemical, mechanical, optical and biological analysis. While the student's were developing a virtual microtechnology, it had to be a logical and realistic novel extension of existing technology. Emphasis was placed on creative new approaches or new systems.

Once tasked with this big picture project, smaller, intermediate milestones were given to the students. The milestones were strategically designed to part by part build into an archival journal article, which was their final report for the Concept Development Project. These milestones were outlined in additional documents throughout the semester, which supplemented the outline and provided details for the 4 progress reports plus the final archival journal article which were due at 2 week intervals. The milestones followed roughly the following topics and skills related to their project:

- Progress Report 1: Introductory description of proposed, novel analytical microtechnology
- Progress Report 2: Literature review on the scientific premises of proposed analytical microtechnology (> 10 references, fully discussed)
- Progress Report 3: Prototype drawing and accompanying description of analytical microtechnology (option open for students to conduct preliminary experiments)
- Progress Report 4: Final device design, first draft of complete final report
- Final Report: Archival journal article format and tone.
- Final Project Presentations

The groups were partially student-choice, partially assigned such that a graduate student was the leader on each team. Graduate student leaders were the central individuals responsible for compiling the final report, which was to be written as a peer-reviewed, archival journal publication, in standard format of the Journal of Electrophoresis. The students were told that the project would be assessed with high standards. For both undergraduate and graduates students, the team output was to include maintenance of a detailed project notebook documenting all members contributions. This was to include "minutes" from each group meeting, records of who brought which article to the meeting, progression of ideas, etc. The information sought in each progress report was clearly communicated to the student teams and the same bullets were used to assess those reports. On a separate page in each of the progress reports, the students were asked to outline the group's goals for the subsequent two weeks as they prepared for the next progress report. This section was to describe each individual's responsibilities. The progress reports are described in turn below.

Progress Report #1: Concept Description & Premise: This progress report was 1-page single spaced (or 2 page double spaced) and was to contain the group's first full description of the large, open-ended, concept development project they would work on as a team effort. The report was to address the following questions and topics for the proposed small-scale technology to address a biomedical application

- What are the broader impacts of the project (who / what would it effect, magnitude of the potential impact)? Why would one be motivated to pursue this idea and potential area of research?
- What is the premise / foundation for your project?
- How is the proposed idea novel from existing technology schemes? A high level overview of related technology that initiated this idea.
- Brief outline of the project development to specifically describe the theoretical and experimental reported technologies in the realm of chemical, mechanical, optical and / or biological analysis that the idea would rely upon
- Preliminary drawing of a rough schematic / block diagram of the device / technology the group will be pursuing.

Progress Report #2: Literature Review: This progress report was to include a review of the current literature to provide the scientific foundation for the premise of the student's projects. It was to include greater than 10 references and needed to fully discuss the findings from each article, the merits and limitations of the reported work, and discuss how the findings from each article related to each other and formed the foundation for the proposed novel idea.

Progress Report #3: Prototype Drawing & Accompanying Description: This progress report was to focus on the device or technology the group had conceived. This was similar to constructing the experimental methods section of the final archival journal article. The progress report was to include an intro to the technology, a prototype drawing of the device and a detailed description and discussion of each component of the device. The concluding paragraph was to cover how the device components were envisioned to work together. The following questions were to be answered in this progress report:

Introduction (A brief one paragraph answering: What is the purpose of the device and who would it benefit? What is the premise / foundation for the concept? How is the project novel from existing technology schemes? Lastly, the students were asked to justify the technology chosen for the device.

- Prototype body (Device drawing must be an AutoCAD (or similar) drawing that is to scale. If more than one view is needed, multiple drawings are encouraged. The students were asked to describe and discuss the purpose of each component of the device. They were also asked to clearly communicate built-in controls (required) to ensure the device / technology was working reliably during each test. Lastly, the students were asked to preemptively note device reliability issues.
- Conclusions: The report was to conclude with a summative, higher level discussion of the overall device and the interactions of the components that would ultimately yield the desired results.

Progress Report #4: Final device design, first draft of complete final report: This progress report was to include a compiled 'Introduction' that described the motivation and need for the device as well as a higher-level description of the device. This was then followed by the student's revised literature review of the field and then focusing statements on the premise of the work and what the reader should expect to learn from reading the paper. The 'Experimental Methods' section was then to cover the technology followed by the revised prototype drawings of the device. The student's were reminded how each section should cross-reference their body of supporting literature and published devices to justify their concept. It can be noted how each progress report comprised a section of this final report as is outlined below:

- Introduction was a revised version of Progress Report #1 and included purpose of device, premise, foundation, and novelty of the idea, and justification of the chosen concept.
- Literature review section needed to provide a detailed discussion of all literature which provided a foundation for the novel project concept. The literature review had to cover the breadth of the field such that all related technologies were mentioned and compared to the student conceived novel idea. The literature also had to cover the depth of specific supporting topics such that realistic values could be given for device volumes or concentrations, and specific molecules / fluorophores were given by name. The students were taught that a thorough literature review could also demonstrate the lack of information in an area and support a) the novelty / need for your idea, or b) the need to develop knowledge in that area. This section was to conclude with an assessment of what the information compiled from the literature meant with respect to their concept.
- Prototype body progress report transitioned into the 'Experimental Methods' section of the final paper. This section had to cover the technology followed by the revised prototype drawings of the device along with detailed descriptions and discussions of each component of the device and its operation. The next part of this section was to describe the technology operation as well as conjectures of the potential data obtained from the device. The concluding paragraph of the experimental methods section was to discuss how device components interacted to yield the desired results.
- Device / technology operation was then included as the 'Results and Discussion' component of the final report. This section included example or expected results and / or a detailed experimental plan on testing for device / technology feasibility or workability. The purpose of this section was to have the student's think through what type of data they could attain and how they would present it to disprove or prove functionality of their conceived design. Within this section, the students also had to discuss the challenges to making the conceived device function properly. They were asked to discuss controls added to the device design to ensure test reliability and any issues during device operation which might compromise the data obtained. The idea of this was a problem mitigation assessment.
- The final section of the final archival journal article report was conclusions. In this section, the students were asked to discuss the overall device and the interactions of the components to yield their final results. Their concluding statements were required to tie into the motivations outlined in the introduction and assess the potential success of this conceptual technology.

Final Report: Edits and extensive feedback was given to the students within two days of turning in their draft of the final report (Progress Report #4). The students were told that the final report needed to be substantially improved from the draft and the completed final report would be graded closely. The final report was turned in concurrent with the final presentations.

Presentations: Final Oral Discussion of Group Concept Project: The final assignment in this course was a formal presentation in Powerpoint (or other). It was required that every member of the team be equally and integrally involved in orally presenting the slide content to the entire class. The presentation had to include all the sections included in the student's final report. The student's were instructed that all sections had to cross-reference literature and build upon the existing published technology. The students were told that content was the most important thing to include and that superficial, pretty discussions would be critiqued heavily. The students were also strongly encouraged to use any additional presentation tools, interactions with the audience, etc.

The students were given the opportunity via formal evaluation sheets to assess their classmates on the final presentations and concept design project. Individual team members were also asked to evaluate their other team members on the metrics of contributions and performance during the semester via a structured evaluation sheet. These scores were compiled and used to adjust the professor's assessment of the final project grade to determine individual grades for the group projects.

CONCLUSIONS

The Benefits of Open-Ended Research Inspired Projects are numerous and apply to the student, the professor and the larger project. Open-ended research inspired projects are intimidating for students, but assessment of the efforts described above have shown that students self-report that they learn more from these projects than they learn from traditional lectures and working problems [Minerick, 3; Prince, 8]. Other research has determined that engagement of students in critical thinking and research increases student awareness of and excitement for science and engineering and the likelihood of retention through bachelor degree programs and therefore the likelihood of matriculation into graduate programs. This approach fosters development of problem solving, information filtering, logic, and concept linkage skills in students. This approach puts the student's in the driver seat to obtain significant background work on the problem to determine if it is feasible, what tools will be needed to solve the problem, and that the necessary information is readily available to them. These students will then enter the workforce or graduate school with experience in teamwork and in approaching tasks requiring problem solving, inquiry based skills such as those encountered in the sciences and engineering fields. This is an initial attempt to connect in the academic environment the skills students desperately need to learn to succeed in industry and graduate school.

This paper described the background on concept development projects and the implementation of these projects in a Biology Honors Course and in an Analytical Microdevice Technology Course. The key components that any professor adopting this technique should pay attention to are to structure and define the expected outcomes of the project early in the process and as detailed as possible. Providing a timeline and a detailed outline of expectations for all student participants is necessary. It is advisable to also include a timeline and list of expectations for the professor and any near-peer mentors (lead undergraduates or graduate students) participating in the concept development project. In addition, the project should be broken down into smaller milestones with a concurrent timeline for the completion of those milestones. Provide structure for fitting those components together and providing substantiative examples and feedback is important. While the actual concept that the students are developing in less defined, the goal and components of the end product should be clearly defined. It is important that everyone involved in this type of project feel some level of ownership in the project, that all individuals need to follow through for the team to succeed, and that their individual as well as their team contributions matter. The authors feel that this concept development project approach to student engagement and learning shows great promise. Students that have had this type of experience self-report that they learn much more about science and engineering and about relevant approaches to solving problems in science and engineering from these concept development projects than they learn from traditional lectures and practice problems.

REFERENCES

1. Aronson, E. 2000. The Jigsaw Classroom. web site by Social Psychology Network: http://www.jigsaw.org/.
2. Johnson, DW, RT Johnson, and K Smith. 1998. Active Learning: Cooperation in the College Classroom, Interaction Book Company ISBN 0-939603-14-4.
3. Minerick, A.R., "Creative Learning in a Microdevice Research-Inspired Elective Course for Undergraduate and Graduate Students", Chemical Engineering Education, in review, 2008.

4. National Research Council. 1996. C.f.S., Mathematics and Engineering Education, From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering and Technology, Report of a Convocation. Washington D.C.: National Academy Press.
5. National Research Council, C.o.U.B.E.t.P.R.S.f.t.[s.]C.. 2003. Bio 2010: Transforming Undergraduate Education for Future Research Biologists. Washington D.C.: National Academy Press.
6. National Science Foundation. 1997. Shaping the Future: New Expectations for Undergraduate Education, Report to the National Science Foundation. National Science Foundation, Division of Undergraduate Education, Advisory Committee.
7. Newell, J.A. “Survivor: Classroom. A method of active learning that addresses four types of student motivation.” Chemical Engineering Education, 39(3), 228-231, 2005.
8. Prince, M. 2004. Does active learning work? A review of the research. Journal of Engineering. Education 93(3):223-231.
9. Prince, M. and Felder, R. 2006 Inductive teaching and learning methods: definitions, comparisons, and research bases. Journal of Engineering. Education 95(2):123-138.
10. Seymour E. and N.M. Hewitt. 1997. Talking About Leaving: Why Undergraduates Leave the Sciences. Boulder, CO: Westview Press.
11. Smith, DA, SD Sheppard, and DW Johnson. 2005. Pedagogies of engagement: Classroom-based practices. Journal of Engineering Education 87-101.
12. Wankat, P.C. 1997. Synergism between research and teaching separations. Chemical Engineering Education 31:202-209.