Problem-based, K-12 Cooperative Engineering Education

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***Abstract* – Introducing high-school students to engineering as more than a casual level may address both technical and social needs of the profession; specifically, students may be more likely to enter a field with which they have some in depth knowledge, increasing diversity and better preparing high school students for rigorous college curricula. This paper discusses one such effort.**

Over a four-year period, the chemical engineering undergraduate fluid mechanics course at Brigham Young University and students in several high school classes, primarily at Mountain View High School, participated in a Fluids Fest. The Fluids Fest was the culmination of a semester-long collaboration that required student teams comprising college and local high school students to: (a) choose a question that "your grandmother would find interesting" and is related to fluid mechanics; (b) perform experiments or otherwise collect verifiable data related to this topic; (c) build an apparatus that demonstrates the central principle involved; (d) write a report documenting the experience, including a technically rigorous explanation of your topic; (e) prepare a poster and presentation summarizing the work; and (f) make a joint high-school-college presentation of the work at the Fluids Fest, a science-fair-style event near the end of the semester. This activity addressed many educational objectives difficult to address in more traditional classroom activities, including issues of practical problem solving, open-ended problems, teamwork, interdisciplinary work, project management, and several forms of communication.

Project evaluations asked students to compare the efficiency of learning in this activity to spending equivalent time and effort in more traditional activities such as homework, quizzes, classroom discussions, etc.

High school students involved in the fluid fest indicated they gained substantial and useful information about engineering generally and their chosen topics specifically.

College students overwhelmingly indicated that the time spent in this activity was more effective and more efficient than traditional classroom experiences. Subsequent student surveys collected from Fluids Fest participants currently in graduate school and industry further indicate that the several real-world aspects of the project proved among the most valuable lessons for student success. Attempts to replicate the experience in other classes generally led to successful results, though not uniformly as successful as in this class. Instructor enthusiasm appears to be a strong determining factor for the project.

Index Terms – problem-based learning, service learning, K-12 education, fluid mechanics.

INTRODUCTION

Problem-based learning programs are attracting increased attention in engineering education practice and research. Denmark's Aalborg University is among the earliest adapters of this education paradigm and remains among the leaders in practice and assessment [1, 2]. In this now 30-year-old program, students spend as much as half of their time working on projects, a quarter taking classes addressing project-specific content, and a quarter in classes in the remainder of the curriculum. Internal and third party assessments indicate the paradigm improves student preparation in areas such as problem solving, teamwork, project planning, communication, leadership, broad technical competence, and diversity. Assessments suggest the paradigm may slightly compromise specialized technical competence such as may be important for graduate students. The paradigm also appears to enhance both enrollment and retention of engineering students.

Research in problem-based education is also increasing rapidly. Figure 1 (note the logarithmic scale) indicates that the number of indexed publications in engineering venues based at least in part on problem-based learning is increasing exponentially based on trends over the past twenty years, as is the fraction of problem-based education papers among all engineering education publications. Consensus conclusions gleaned from these articles indicate that problem-based learning: (1) improves group skills such as teamwork, communication, and leadership; (2) improves individual skills such as innovation, entrepreneurship, planning, problem-solving, and writing; (3) provides useful outcome-based assessment metrics for both individuals and programs; (4) can mitigate curriculum overcrowding; (5) greatly increases student engagement in learning; and (6) enhances academic and industrial interaction [3-9].

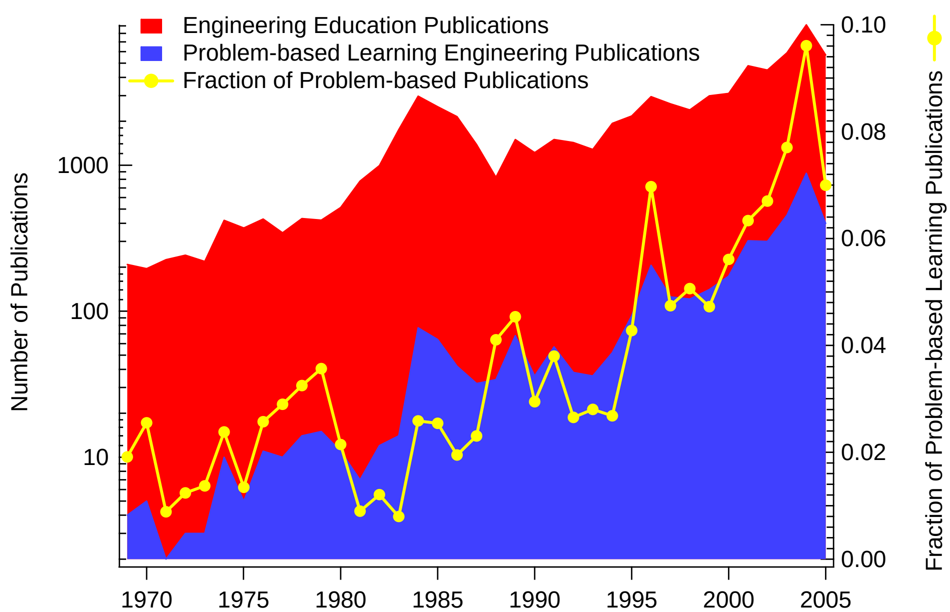

Figure 1 Number of problem-based learning publications in engineering-related forums as a function of year.

Such documentary summative information generally provides overly optimistic impressions since researchers infrequently report negative experiences, but the evidence suggests that adjustments to problem-based courses and programs involve significant resistance from students, faculty, and institutions accustomed to traditional approaches. Nevertheless, there now exist positive case studies for problem-based learning that span all engineering disciplines, address course levels from freshman through graduate school, and include scopes ranging from single classes to whole programs.

The literature forms a solid case for problem-based instruction and its systematic evaluation, and it could appear that the data recorded here result from careful planning based on these documents. Such was not the case. While the author was and remains closely associated with some of the leading institutions in this field, this document records the results of a single faculty member trying to provide more participatory experiences for students in one rigorous course with perhaps only slightly more planning than a busy schedule allowed and than the events demanded.

THE FLUIDS FEST

This document describes experiences with the Fluids Fest, a problem-based learning experience within an otherwise traditional (mostly lecture-based) course for chemical engineering juniors. The primary motivations for this activity include to: (a) help students discover the fascinating world of fluid mechanics; (b) build student competence and especially confidence in the skills they are learning; (c) enhance K-12 technical education; and (d) enhance student and instructor enjoyment (fun) during the semester.

The Fluids Fest is the culmination of a semester-long activity in which about 25 small (2-3 students) university student teams join slightly larger (3-4 students) local high school teams to to form 5-7 person teams that: (a) choose a question that "both you and your grandmother find interesting" and is related to fluid mechanics; (b) perform experiments or otherwise collect verifiable data related to this topic; (c) build an apparatus that demonstrates the central principle involved; (d) write a report documenting your experience, including a technically rigorous explanation of your topic; (e) prepare a poster and presentation summarizing your work; and (f) present the work as a team at the Fluids Fest, a science-fair-style event near the end of the semester.

Each of these characteristics addresses specific goals of the project. Self-selecting topics of general interest and hopefully common experience (depending on grandmother's background) helps establish connections between coursework and student's experience base. The self-selection portion also encourages innovation and topics beyond the instructor's experience base. Collection of real data encourages student familiarity with instrumentation, experiment, statistics, and safety. Building a demonstrative apparatus invites dramatic innovation and greatly enhances the culminating presentations. The report provides valuable documentation for the high school instructor and invaluable writing experience for the students. With the exception of a single section that was to include a rigorous, quantitative description of their project, the reports were to be written at a high school level – possibly the most common and useful writing level for technical communication outside (and possibly inside) the research community. Preparing and presenting the results in poster format enhances oral communication skills and develops an appreciation for art, style, and aesthetics in presenting technical information. Finally, having the high school students report the results to the instructor on the night of the Fluids Fest with the college students standing at their sides places students in instructor roles, greatly enhancing the depth, and breadth of their understanding.

A CARICATURE OF BYU CHEMICAL ENGINEERING UNDERGRADUATES

BYU is an atypical university with atypical students, and many of the defining characteristics of each possibly relate to but do not predispose the results of this project. These are summarized here.

I. Brigham Young University

Brigham Young University (BYU) is a private university sponsored by the Church of Jesus Christ of Latter-day Saints. It is a relatively large (appx. 33,000 students) university with twelve colleges spanning essentially every traditional technical, humanities, social, and professional discipline. The Fulton College of

Engineering and Technology within BYU includes four major engineering disciplines (chemical, civil and environmental, electrical and computer, and mechanical) and a School of Technology. The engineering disciplines all offer BS, MS, and PhD degrees and the programs in the School of Technology commonly offer terminal degrees (generally not PhD) in their respective disciplines. BYU graduates among the most engineering majors in the several-state intermountain region (Montana, Idaho, Wyoming, Nevada, Utah, Arizona, New Mexico). None of these aspects is unique among universities.

BYU primarily focuses on undergraduate education, though the institution actively supports graduate schools in many departments, with those in engineering being among the most active on campus. The research programs on campus must support the overall education mission rather than becoming ends to themselves, and this commitment to education permeates policies and practices from the faculty to and including the Board of Trustees. BYU does not aspire to be an academically elite research university – the administration and faculty prefer that any student supporting its values and desiring to attend should be able to attend. Nevertheless, the combination of enrollment caps and strong demand from accomplished students results in a highly capable and statistically elite student body, as discussed below. Education represents one of several widely shared social values of the sponsoring church and therefore the great majority of the students. BYU strongly supports a holistic educational approach, combining moral standards with education as one of its founding principles. An Honor Code defines student and faculty expectations and, in addition to discouraging cheating and unlawful conduct as do most universities, defines alcohol or tobacco consumption, extramarital sex, and sloppy or radical dress and grooming standards as unacceptable, dismissible offenses. These standards generally represent attractions to BYU for faculty and students rather than impositions and they help define a campus culture uncommon among universities. Many campus survey programs rate BYU as one of the most serious academic environments and the most "stone-cold sober" campus in the US. The sober designation relates to (a lack of) alcohol or other drug consumption, etc., not student interaction. Faculty and especially students maintain very active social lives, as is encouraged through both campus activities and student-based congregations that meet weekly on campus. The university maintains a relatively modest tuition rate, especially by private school standards, and a very active student employment and scholarship program so that financial barriers prevent no student from attending (annual tuition ranging from $3400 to $5000 at the time of the work reported here, depending on undergraduate/graduate status and church affiliation). BYU is conservative by any measure (politically, administratively, fiscally, socially, and academically). However, the university encourages innovative and effective teaching and generally fosters an amiable rather than hierarchal student-faculty relationship. Most universities develop a sense of camaraderie among faculty while struggling with individual, inter-departmental and inter-college competition for funds and recognition. BYU is no exception. However, the culture and spirit of shared mission on campus enhance cooperation and mollify much of the competition and, with it, many of the barriers to sharing resources. In any case, the projects discussed in this document depended heavily on equipment and expertise from technology programs, mechanical and electrical engineering, physics, sports programs, research labs, and other campus resources, all of which responded both positively and generally enthusiastically.

II. BYU Students

BYU students dominantly are members of the sponsoring church, though that is not a requirement to attend. The campus draws students from all 50 states in the US and typically over 65 other countries, though the US citizens dominate the demographics. The great majority of the engineering students at BYU have lived abroad for about two years in conjunction with voluntary and self-financed church service. Consequently, these students have language skills and a service ethic uncommon and possibly unmatched in aggregate by any other US university. The students involved in the project described in this paper average SAT/ACT scores above the 97th percentile, which is typical for the chemical engineering department and only slightly exceeds the numbers for the college and university. Because of the service to the church, upperclassmen tend to be about two years older than those in comparable positions at other universities. All of these student attributes contribute to but do not predispose the success of the program described below.

EMPIRICAL EDUCATION-RELATED RESULTS

During each year of the Fluids Fest, both high school and college students self report their impressions of the educational benefit of the activity. The survey included both free-response and selected-response questions. The free response questions included identifying the most educationally beneficial aspects of the experience, the most significant things learned, and suggestions for improvement. The selected-response questions summarized in this paper asked students to indicate how strongly they agree or disagree with the following question: "Doing a hands-on project substantially improves the learning experience in this course, that is, the time spent doing the hands-on aspects of this project contributed more to learning than an equivalent amount of time would have in more traditional (classroom) activities." The range of responses increased each year, beginning with a simple agree/disagree and ending with a seven-level response ranging from "very strongly agree" to "very strongly disagree." Other questions relate to the service learning, high school interaction portions of the project and will form the content of a second paper. However, in summary, these were generally positive but less positive than the problem-based learning aspects reported here.

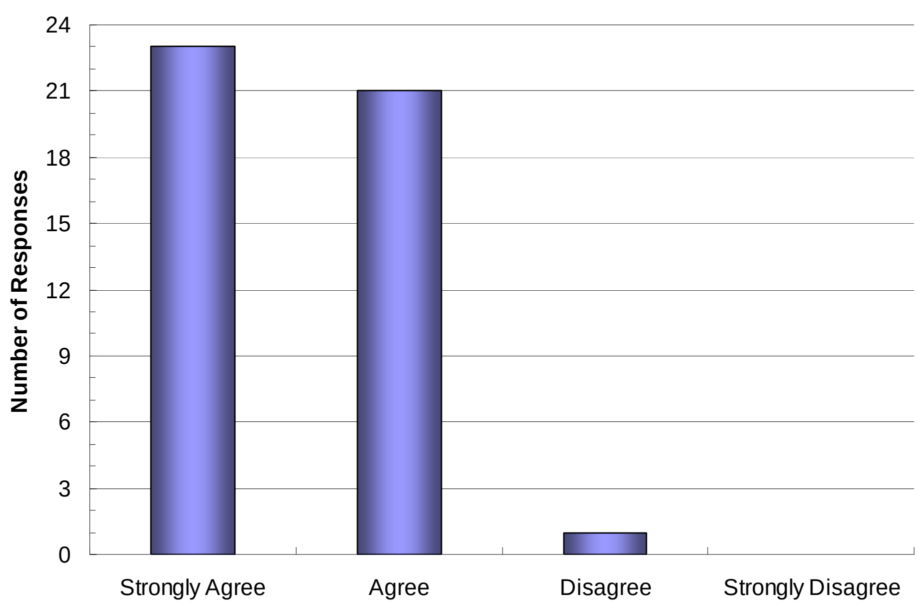

Figure 2 Summarized student evaluations of hands-on learning effeictiveness – Second-To-Last survey.

A summary of college student evaluations of their experience in the Fluids Fest in the last two years appears in Figure 2 and Figure 3. These data are indicative of the previous two years but provide more resolution in responses. As indicated, the response is overwhelming positive, with one student expanding the upper end of the scale with a more extreme write-in vote in the last year and less than 3% of the students returning negative responses. The entire class returned surveys, with 100% responding to this question in the data summarized in Figure 2 and 93% responding to this question in Figure 3.

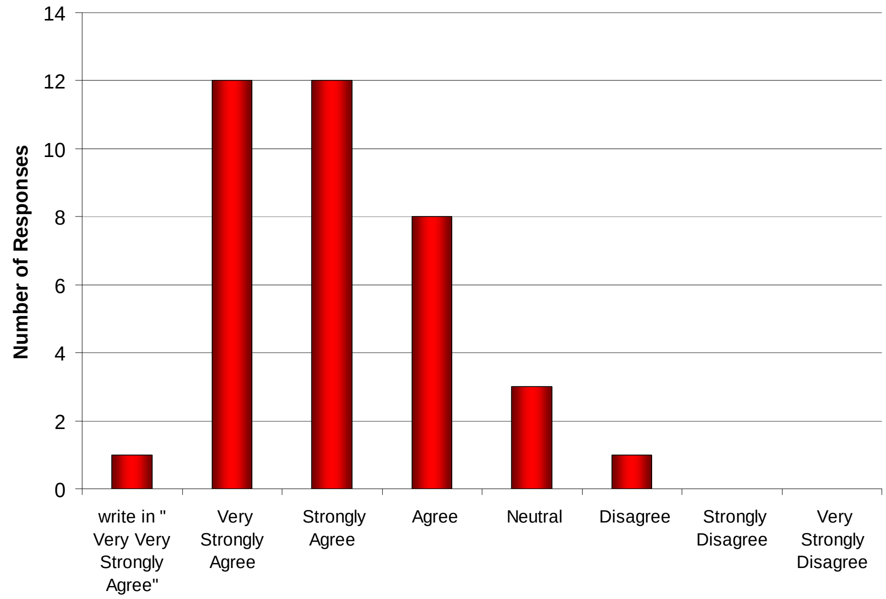

Figure 3 Summarized student evaluations of hands-on learning effeictiveness – last survey.

This comparative evaluation could either reflect effectiveness of the problem-based learning exercise or ineffectiveness of the remaining instruction. Comparisons of the student view of this class compared to their remaining classes suggest that it is an endorsement of problem-based learning. Specifically, students rate all courses and instructors at BYU each semester, with responses in 22 categories on a 1-8 scale, 8 representing a positive experience. On an absolute scale, the two most general scores (overall instructor and course evaluation, respectively) for this course were 7.4 and 6.6, both well above campus, college, and department averages. Relative to courses taught in the department, college, and university, the average scores for this course exceeded those in the department and college in all 22 categories and those at the university as a whole in 20 of the 22 categories. The course scores exceeded those of the department, college, and university by statistically significant margins 91%, 91%, and 73% of the time, respectively. In addition to exceeding the local norms, these numbers exceed the instructor's norms for teaching. This was a demanding course. Students reported spending 3-4 times as much time in this course as the average for other courses and the average GPA was the lowest of any course in the department. Fluid mechanics is an enjoyable if challenging course to take and teach, and this influences these scores significantly. Nevertheless, these course assessments indicate that the responses shown above endorse problem-based learning rather indicting the remainder of the course.

SUBJECTIVE STUDENT RESPONSES

Student self-reported evaluations included ratings of all student projects based on visiting each demonstration during the Fluid Fest and several free-response questions. The most relevant information to this paper from the free-response categories came from the questions "The three most significant things I learned doing these projects are:", "The greatest contributions of the activity to learning are:", and "This project could best be improved by:"

The query asking for the three most significant things learned drew responses split roughly evenly among three types: (1a) specific technical information learned from the demonstrations; (1b) technical information associated with doing projects generally; and (1c) interpersonal and other non-technical issues generally associated with working as a team. Commonly, individual students responded in two or all three of the above categories. The technical information corresponded to the topics of any given year but were more evenly distributed among those topics than were the evaluations of the demonstrations. That is, students did not uniformly list the content of the demonstrations they ranked as best or even the ones that they personally performed as the ones that necessarily taught them the most significant technical content. Example responses of technical things learned include: “The secret of Bose Speakers,” “How a curve ball works,” “What a shock wave is,” “How a toilet works,” and “How to sail into the wind.” Commonly, topics chosen for demonstrations and ranked highly were either much more detailed examples of topics covered in class or subjects only lightly mentioned, if at all. The Fluids Fest demonstrably expanded the scope of topics to which the students were exposed and the students were most generally accurate and thorough in their explanations.

Common responses dealing with technical projects generally revolved around (2a) dealing with experimental data, both its scatter and interpreting its trends, (2b) the importance of sticking to a schedule to complete the project in time, (2c) communication, especially with the off-campus team members, (2d) resourcefulness and innovation in developing demonstrations using mainly the high school student’s garages for construction material, and (2e) many vagaries of teamwork. Typical responses include “Understand what you are supposed to do from the beginning,” “Creativity is an important part of any experiment,” and “Don’t be afraid to do research and find out for yourself when you don’t have an answer key.”

Responses centering around interpersonal issues generally focused on: (3a) keeping an entire team engaged in the project, (3b) discovering more capacity and willingness among peers and team members than suspected, and (3c) discovering the capacity of others to learn. Typical responses include, “Even complex principles can be understood by those willing to learn,” and “The value of an interdisciplinary approach to address different aspects of a project.”

Those seriously engaged in ABET standards A-K will recognize in these responses elements of many of the non-technical skills that are now formally part of the engineering educational mission but that traditional class-room-based teaching sometimes inadequately addresses. Furthermore, students cite the value of these skills based on individual experience in natural and pragmatic terms rather than theoretical, rehearsed, or philosophical contexts. The successes of this project bringing out these skills without doubt stem at least partially from the nature of the students who, as previously outlined, generally maintain a strong focus on their education and share an enthusiasm for cooperation within their community.

Responses to the query, “The greatest contribution of the activity to learning are:” also varied widely. Many students commented that they were impressed that the principles they learned in the class actually corresponded to what they measured in the projects, bolstering their confidence in both their understanding and the utility of the classroom material. Many commented on the difficulty of coordinating group efforts. Some students indicated they were disappointed while others indicated they were very positively impressed with the cooperation of the high school students and with their teammates. No apologies were offered for the potential difficulty of coordinating the group schedules and division of labor. On the contrary, the instructor admonished the students that effective team work, communication, and scheduling will be an integral portion of their professional careers and their facility for such coordination is one of the major distinguishing factors in their success. There is no better time than now to develop the skills needed to form effective teams and keep them focused.

With respect to issues that could best be improved, the majority of students commented on planning and execution issues including communication, scheduling intermediate deadlines, scheduling meetings with others, etc. The project involved several intermediate milestones and started with developing Microsoft-

Project™-based instruction on scheduling group work, but students generally felt they would have performed better if there had been more consequence to missing the intermediate deadlines and more structure in the class supporting the projects.

FACULTY PERSPECTIVES

Faculty support within the department and college for this effort was ambiguous. Several of the faculty expressed interest in the project and some started similar projects, though not as extensive, in other courses. Less than 10% of the faculty visited the Fluid Fest personally (a total of 5 visits over four years involving two individuals out of 13 faculty members). The timing of the event (evening near the end of the semester) perhaps made it difficult for many individuals to attend. Useful but commonly critical feedback from faculty expressed their concerns, which included too demanding of students' and instructor's time, unclear pedagogical benefits, lack of focus on a few fundamental principles, and general resistance to change. These criticisms only partially abated after circulating assessment results to interested faculty. The project was cited in ABET documents as helping to address some of the A-K issues sometimes overlooked in traditional classes.

The class instructor perspective is not ambiguous. The instructor both recognizes and appreciates the experience and wisdom of his colleagues and their focus on quality teaching. However, his enthusiasm for this activity and its potential contribution to effective, relevant teaching loom large. Indeed, it is probable that the instructor's enthusiasm for the activity in large measure influences the student responses cited earlier. This activity was not undertaken lightly. The specific pedagogical aims driving this project include (1) creating an environment in which students became teachers as a mechanism to motivate more thorough mastery of the material; (2) addressing learning styles frequently overlooked in many traditional classroom settings; (3) creating realistic settings for teamwork, interdisciplinary cooperation, innovation, communication, and discovery, and (4) creating an opportunity for engineering students to do exciting engineering things and learn to use a host of meters and devices to solve a problem. The experience turned out better than the instructor dared hope. Some of the unique characteristics of both BYU and BYU students undoubtedly contribute to this, such as their general willingness to work hard, their commitment to education, their considerable organization skills, etc. However, based on experience with students at many campuses, both elite and egalitarian, most engineering students would benefit from such projects.

LOGISTICS

A few logistical details are worth mentioning. The first report the students were to complete was a safety review. Among other things, this was to identify all hazards associated with their project and mitigation strategies. Some projects were rejected (generally those involving open flames, excessive pressure, and homemade electrical devices handling more than 24V).

The liability of having high school students involved is substantial and may give many administrations pause. In this case, the class was organized as a service learning activity (the results of which are separately reported in a companion paper) and qualified for service-learning-liability considerations from the administration, greatly reducing the paperwork that would otherwise be required.

The equipment, posters, etc. require money. The posters were printed professionally on campus equipment and cost about $15 for a 3'x4' color print. This is far below the cost of the same poster from private printing companies and if such inexpensive resources could not have been found, the cost may have become prohibitive. Most of the costs of equipment were minor as most teams made their demonstrations from spare parts in local families' garages. However, we did offer a nominal budget for each group for equipment that is not found in garages. Finally, the Fluids Fest culminated with a pizza dinner for the high school and college students at a cost of roughly $350. All told, the Fluids Fest cost a little less than $1k per festival, with most of that being for pizza and printing posters. These funds were secured from several sources over the four-year lifetime, occasionally being donated by the college because of the interaction with high schools, occasionally being donated by the campus service learning center, and occasionally being supplemented by private funds.

The university gladly made the central hall of our student center available for the Festival at no fee. This or some similar high-traffic location is ideal and the random appearance of passersby and this setting helps add to the spontaneity and excitement of the evening. We tried but could never succeed in getting a local mall to allow us to use their halls, mainly because the event came too close to Christmas, a time when mall space is very dear.

Equipment that continually surprised the instructor for both its sophistication and its relevance came from the athletic departments. These departments have many ready-built machines for measuring, for example, trajectories of pitched baseballs, drag on javelins, etc. Other departments who helped make this successful include the Physics, Technology, Chemistry, and all engineering departments.

LONGITUDINAL RESULTS

Our hope is to complete a more formal longitudinal study of the Fluids Fest participants with response rates comparable to those shown for the earlier data, but despite efforts to do so, longitudinal surveys of students at this point can only be characterized as anecdotal. These, nevertheless, provide some important information. They come from students who have gone on to graduate school, industrial positions, and other professional schools.

Most students remain very positive about the experience and its educational merit. Some mention it as one of the most useful things they did as undergraduates to help prepare for real-world positions. Several indicate this realization came only after leaving school. A small minority feels it was too much of a distraction from class work, though they seem to have mostly fond memories of it. Several indicate that more rigid intermediate goals would have improved the experience. None has expressed hostile or deeply critical comments about the experience.

CONCLUSIONS

Problem-based learning represents a supplemental teaching paradigm that addresses many of the non-traditional skills required by new accreditation procedures and, more importantly, essential to working in most academic and industrial settings. Specifically, problem-based learning (1) improves group skills such as teamwork, communication, and leadership; (2) improves individual skills such as innovation, entrepreneurship, planning, problem-solving, and writing; (3) provides useful outcome-based assessment metrics for both individuals and programs; (4) can mitigate curriculum overcrowding; (5) greatly increases student engagement in learning; and (6) enhances academic and industrial interaction. The Fluids Fest is one example of how problem-based learning can supplement traditional class room instruction.

The success of the Fluid Fest depends on several things, possibly in this order: (1) the enthusiasm of the instructor; (2) the maturity and focus of the students; and (3) the cooperation of the institution. The activity would not be successful without all three components.

As with any other change, implementing problem-based learning in the curriculum generally meets with some growing pains and sometimes considerable criticism. However, the educational benefits in this case outweigh the legitimate concerns of the faculty.

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REFERENCES

1. Kjersdam, F. and S. Enemark, *The Aalborg Experiment: Project Innovation in University Education*. 1994, Aalborg: Aalborg University Press. 52.

2. Kolmos, A., F.K. Fink, and L. Krogh, eds. *The Aalborg PBL Model: Progress, Diversity and Challenges*. 2004, Aalborg University Press: Aalborg, Denmark. 400.

3. Bowe, B., et al., *Teaching physics to engineering students using problem-based learning.* International Journal of Engineering Education, 2003. **19**(5): p. 742-746.

4. Chau, K.W., Problem-based learning approach in accomplishing innovation and entrepreneurship of civil engineering undergraduates. International Journal of Engineering Education, 2005. **21**(2): p. 228-232.

5. Ditcher, A.K., Effective teaching and learning in higher education, with particular reference to the undergraduate education of professional engineers. International Journal of Engineering Education, 2001. **17**(1): p. 24-29.

6. Smith, K.A., et al., *Pedagogies of engagement: Classroom-based practices.* Journal of Engineering Education, 2005. **94**(1): p. 87-101.

7. Williams, K. and G. Pender, *Problem-based learning approach to construction management teaching.* Journal of Professional Issues in Engineering Education and Practice, 2002. **128**(1): p. 19-24.

8. Felder, R.M., *An educator for all seasons.* Chemical Engineering Education, 2004. **38**(4): p. 280-281.

9. Felder, R.M. and R. Brent, The intellectual development of science and engineering students. Part 2: Teaching to promote growth. Journal of Engineering Education, 2004. **93**(4): p. 279-291.

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