AC 2009-116: THE EFFECT OF IMPROVEMENTS IN SOPHOMORE DESIGN INSTRUCTION ON PERFORMANCE IN SUBSEQUENT COURSE OFFERINGS

Kevin Dahm, Rowan University

Kevin Dahm joined the Rowan University Chemical Engineering Department in 1999 after earning his B.S. at WPI (92) and his PhD at MIT (98). He has published papers in the areas of assessment of student learning, process simulation in the curriculum, and the teaching of design and engineering economics. He has received the 2003 Martin Award, the 2004 Fahien Award and the 2005 Corcoran Award from the Chemical Engineering Division of ASEE.

William Riddell, Rowan University

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Abstract

The chemical engineering curriculum at Rowan University includes a team-taught, multidisciplinary sophomore course sequence called Sophomore Engineering Clinic I and II, intended to teach engineering design and technical communication. Prior to 2005, Sophomore Clinic I featured a semester-long design project. The faculty team made substantial changes to the course in the Fall of 2005 to address various shortcomings in student achievement of the course goals. The new course design featured a 4-week project intended to introduce students to the process of parametric design, followed by a 10-week project similar to the former semester-long project. The course also implemented an explicit model for the design process; the Converging-Diverging model for design proposed by Dym in 2005[1]. Students were required to document specific design activities, characterize these activities as either convergent or divergent thinking, and demonstrate how their design decisions were informed by both.

A previous ASEE publication[2] demonstrated that the revised Sophomore Clinic I led to dramatic improvement in student designs, as well as being more popular with the students. This paper will address whether the changes implemented in the Fall of 2005 had a lasting impact beyond Sophomore Clinic I. The other two required courses in the chemical engineering curriculum that have substantial design content are Sophomore Clinic II and the senior capstone design course. The Fall 2004 and Fall 2005 Sophomore Clinic cohorts have now completed the curriculum. This paper presents a comparison of their performances in Sophomore Clinic II and Chemical Plant Design, as well as summarizing the converging-diverging model for design and the specific changes made in the Fall of 2005.

Introduction

The Sophomore Engineering Clinic is a sequence of two team-taught, four semester-hour courses. The faculty team for each semester consists of at least two instructors from the College of Communication and at least five from the College of Engineering, with each of the four Rowan engineering disciplines (Chemical, Civil and Environmental, Mechanical, Electrical and Computer) represented. Each student has two 75-minute lecture periods and one 160-minute lab period per week.

During the lab periods, students work on design projects, supervised by engineering faculty. Lecturing is provided as-needed to instruct students on design principles and facilitate the projects, but the bulk of the lab time is provided for students to work with their teams. During lecture periods, Communication faculty provide instruction on technical communication (technical writing in Sophomore Clinic I, public speaking in Sophomore Clinic II) using the design projects as a context. Many of the course deliverables for Sophomore Clinic I and II are writing assignments and presentations about the design projects, which are graded jointly by engineering and communication faculty. This two-course sequence is consistent with growing national trends of integrating design into the early years of the curriculum[3,4,5] and stressing the importance of communication skills[6,7,8]. The sole learning objectives of the course are engineering design principles and technical communication; there are no discipline-specific learning objectives. The design projects tend to be multi-disciplinary in nature but there is no expectation that all Rowan engineering disciplines will be equally represented in every project.

Prior to Fall 2005, each semester had been structured around a single, semester-long design project. During the Fall of 2005, two major changes were implemented in Sophomore Engineering Clinic I:

- A sequence of two projects was used: a four-week project intended to teach parametric design, followed by a more open-ended 10-week project. This allowed students to complete and write a final report on an engineering design project, receive feedback, and apply lessons learned through this process to the main design project.
- The Converging-Diverging Model for design[1] was presented. Students were required in their reports to document evidence of both convergent and divergent activities, and show how final design decisions were informed by both.

The design projects, and the changes to the course that were implemented in the Fall of 2005, are summarized in the following sections and were described in more detail previously.[2]

The Converging-Diverging Model of Design

Dym, et al.**Error! Bookmark not defined.** proposed a model for design as an alternating series of divergent and convergent inquiry. Convergent thinking is the process of determining verifiable facts. By contrast, when practicing divergent thinking, "the questioner attempts to diverge from facts to the possibilities that can be created from them."**Error! Bookmark not defined.** When following Dym's model, the designer begins with a goal and a divergent, creative exploration of possible approaches. This is followed by using convergent inquiry to assess the feasibility of each approach. The facts learned in this convergent step could provide definitive evidence that one approach is "best" and an optimized solution. However, the convergent step could also give rise to new ideas, call into question assumptions made, or reveal that the "best" solution is still not sufficient to meet the designer's goals; circumstances which would necessitate another divergent step. Dym, et al. observe that typical engineering students have experienced years of homework and test problems with unique "right" answers, and thus are much more practiced in convergent thinking than divergent thinking.

The Hoistinator Project

In the Fall 2003 and Fall 2004 semesters, the semester-long design project was a crane design project called the "Hoistinator", which was described in detail previously.[9] Figure 1 shows the "base unit," consisting of an I-beam, motor and stack of weights (up to 20 identical 70 lb weights). This base unit was constructed before the start of the semester and was used by all student teams. Teams of 4-5 students were challenged to design and build a truss, using the materials summarized in Table 1. The truss would be attached to the base unit, allowing the weights to be lifted to a height of at least 36 inches. The teams were also required to build a digital timer circuit that would measure the time elapsed between when the weight left the ground and when the weight reached a height of 36 inches. Students were also required to design and build a digital timer circuit that would measure the time required to reach a height of 36 inches.

Table 1: Structural Materials Allowed for Crane Construction

Aluminum	Alloy: 2024-T3 Max volume: 75 in^3 Stock: ½" and ¼" bar stock available in widths between ½ and 1½" in ¼ inch increments, no length greater than 48"
Plastic	Type: TIVAR UHMW (Ultra-high molecular weight) Max volume: 75 in^3 Stock: ½" and ¼" bar stock available in various widths between ½ and 1½", no length greater than 48"
Fasteners	½-13 and ¼-20 SAE Grade 5 hex cap screws with nuts

The students' goal was to build a truss capable of *supporting a large amount of weight while minimizing use of material*, and to build the most accurate timer possible. These goals were quantified using the "performance equation":

$$Performance = \left[\frac{W}{420}\right] \times \left[1 - \left|\frac{t_m - t}{t}\right|\right] \times \left[\frac{3.5}{LCA_{p-d}}\right] \times \left[\frac{435}{PW}\right]$$

Where

- W is the weight lifted by the crane (lb)
- t is the actual time used to lift the weight (measured using the official timer built by the instructors)
- t_m is the time measured with the student's timer. (A stipulation was made that if the term $\left[1 - \left|\frac{t_m - t}{t}\right|\right]$ was below 0.25 it would be set equal to 0.25, to prevent negative performance values, etc.)
- LCA_{p-d} is the Life Cycle Assessment Eco-indicator points, calculated by ECO-it[10] software, associated with the production and disposal of materials used in the crane. The value 3.5 corresponds to a truss that used the maximum allowable amounts of aluminum and plastic.
- PW is the present worth of costs associated with production, use, and disposal of the crane (in dollars). The value 435 corresponds to a truss that used the maximum allowable amounts of aluminum and plastic.

Students were not allowed to test their cranes before a final competition, which was held on the last lab day of the semester. During this competition, each team attempted three test lifts: the first using 420 pounds, the third using the maximum 1400 pounds, and the second could be any intermediate weight chosen by the team. W in the performance equation is the largest weight successfully lifted and returned to the original starting position. The success of a truss design was evaluated solely by this equation, and counted for 20% of the course grade. The final report describing the project was also worth 20% of the course grade. Each team also completed two progress reports, 1/3 and 2/3 of the way through the project.

After two offerings, the faculty team noted several strengths of the project:

- The scope was judged reasonable for a semester long project, as every team (46 teams over the two semesters) was able to fabricate a crane capable of lifting at least 420 pounds, and over 75% of the teams lifted the full 1400 pounds.
- The project is recognizable as a practical engineering challenge that included aspects from a variety of disciplines
- The project was popular with students as demonstrated by the course evaluation results in Table 2.

However, the faculty team noted limitations in the approach of most teams to the project, primarily with respect to design of the truss. Specific observations included:

- The performance equation was the sole metric for quality of the design, yet fewer than half of the first progress reports mentioned the performance equation in their summary of "design objectives."
- Most teams provided a diagram of their "final truss design" in the second progress report, but many gave only a qualitative rationale for why it was considered optimal.
- By the final report, every team had completed a detailed static and failure analysis of the crane they actually built, but very few teams showed evidence that they had analyzed alternatives quantitatively.

In sum, important design decisions were made early in the process and without a sound basis, and despite faculty feedback on the progress reports, these decisions were in many cases apparently never revisited. These observations are consistent with Dym's generalizations regarding convergent and divergent inquiry. Students showed relatively little evidence of divergent thinking. Students did an excellent job of performing calculations and answering factual questions, and in that sense were effective at convergent thinking, but in many cases the facts obtained were not effectively used to inform actual decisions.

The next section describes the Fall 2005 offering of the course, which incorporated the converging-diverging design model as an explicit focus.

Fall 2005: Revised Course Structure

The Fall 2005 offering of Sophomore Clinic I incorporated a modified version of the Hoistinator project, preceded by a 4-week startup project on building rockets out of soda bottles. A detailed description of the bottle rocket project was published previously.[11] Many schools are using various versions of soda bottle rocket projects in science education[12,13] and NASA has proposed standards and lesson plans for grade 5-12 students.[14]

Constraints and specifications for the bottle rocket project were as follows:

- The goal was to design a bottle rocket that would fly as far as possible.
- The body of the rocket was a 2-L soda bottle.
- Modeling clay was used to add ballast to the bottom of the bottle, which became the nose of the rocket. Clay could not be placed anywhere but the nose.
- The bottle was partially filled with water. No other liquid could be used as a propellant.

- Wings were made out of foam board. Students were required to make 3 identical wings and space them evenly around the circumference of the rocket.
- Duct tape could be used to secure the wings and clay to the bottle.
- No additional building materials other than foam board, clay and duct tape were permitted.
- The air inside the rocket was pressurized to 60 PSI and the rocket was launched at an angle of 45 degrees.
- "Distance flown" was measured perpendicular to the plane of the launcher; thus, students strove to design rockets that would travel far and straight.

Consequently, students had three parameters they could vary: the amount of clay in the nose, the amount of water used as propellant, and the size and shape of the fins. The project was completed in teams of 3-5 but each student wrote an individual, final report on the project. The model of design as an alternating series of divergent and convergent steps was covered explicitly in class, including circulating portions of Dym, et al.'s article. Students were required to identify actions taken by the team, categorizing them as "divergent" or "convergent" thinking, and providing a quantitative rationale for final decisions regarding the three parameters. Typically, student characterized brainstorming possible fin configurations as their main divergent task and finding the optimal values for individual parameters as the main convergent task.

The ten week Hoistinator project used the same crane substructure and materials summarized in Table 1. To streamline the project for the shorter time period, the present worth analysis and LCA were eliminated, and this simpler performance equation was used:

$$Performance = \left[\frac{W}{C}\right] \times \left[1 - \left|\frac{t_m - t}{t}\right|\right]$$

Note that evaluation of the timer is here identical to previous years, and performance is still directly proportional to weight lifted. However, C represents the purchased cost of aluminum ($2 per kilogram) and plastic ($0.80 per kilogram) used in the truss. While this performance equation differs from the previous years, it maintains the fundamental emphasis on designing an efficient structure. Lectures on statics, failure analysis and circuit design were presented as in previous years, but this time with an emphasis on how each of these activities fit into the convergent-divergent approach to design. Broadly, students characterized brainstorming possible truss configurations as divergent thinking. Once a particular truss configuration (number and placement of members) was identified, several convergent tasks (determining forces in each member for a given load, failure analysis to determine minimum width of aluminum or plastic required to withstand the force, etc.) are necessary to design the optimal truss within that configuration.

Comparison of Fall 2005 to Fall 2003/2004 within Sophomore Engineering Clinic I

Anecdotal observations, course evaluations and a comparison of truss performances were used to assess the changes made to the course in the Fall of 2005, and all indications were that the revised course structure led to a substantial improvement. A complete presentation of the assessment was published previously[2]. A brief summary of the assessment results is given here:

- Student evaluation of the project improved in Fall 2005, as shown in Table 2.
- Many of the final reports on the bottle rocket project provided little data and limited quantitative rationale for decisions; identical to the primary shortcoming in the 2003 and 2004 Hoistinator projects. The advantage of the two-project structure was that students received graded feedback and had the opportunity to apply the lessons learned to the 10-week project.
- In the Hoistinator reports, teams typically characterized brainstorming possible truss configurations as "divergent thinking" and optimization within a particular truss family (e.g., determining minimum member thickness to bear a specific load) as "convergent thinking." While these characterizations did not necessarily show any deep insight, they were substantially correct. The requirement of documenting convergent and divergent thinking thus successfully ensured that teams would, at least broadly, engage in convergent and divergent thinking.
- The improved approach used by the Fall 2005 students led to significantly better designs. As shown in Figure 2, the Fall 2005 cohort, when evaluated using the Fall 2003/2004 performance equation (which they had never seen), significantly out-performed the two previous cohorts. In 2005, approximately 50% of teams exceeded the 2004 winning score, and approximately 70% exceeded the 2003 winning score.

Table 2: 2004 and 2005 student evaluations of Sophomore Engineering Clinic

Question	**Mean Response: 5=strong agree, 1=strong disagree**	
	2004	**2005**
This course assisted me in developing teamwork skills	3.82	4.32
This course assisted me in developing multidisciplinary engineering design skills.	3.70	4.06
This course assisted me in developing project management skills.	3.93	4.24
This course helped me make the link between engineering design and writing.	3.89	4.02
Number of respondents	104	108

Impact of Revised Course Structure on Future Courses

The remainder of this paper examines whether the new structure for Sophomore Engineering Clinic I had a positive impact on the students that lasted beyond the Fall of 2005. Two subsequent courses were examined:

- Sophomore Engineering Clinic II, taken by all engineering students in the spring of sophomore year.
- Chemical Plant Design, taken by all chemical engineering students in the spring of senior year.

In the Spring 2004-2006 semesters, Sophomore Clinic II incorporated a semester-long design project on improving the energy efficiency of campus buildings[15,16]. The project itself and the course instruction were essentially identical in 2005 and 2006 (though different buildings were examined), the faculty team was the same both semesters, and the converging-diverging model, introduced in the fall of 2005, was NOT discussed further in the spring of 2006. Table 3 shows that the 2005 and 2006 cohorts were essentially identical in high school GPA and SAT scores.

In sum, the faculty did their best to ensure that there was no significant difference between the two cohorts that could affect their performance on the energy audit project, apart from their different experiences the previous semester in Sophomore Engineering Clinic I.

Table 3: SAT and High School Class ranks for the spring 2005 and spring 2006 Sophomore Clinic II cohorts.

Cohort	Spring 2005	Spring 2006
Average SAT	1232	1230
Average HS class rank	Top 17%	Top 18%

Assessment of the final reports from the energy audit project was conducted using rubrics previously published in *Chemical Engineering Education*.[17] These rubrics were designed to provide an objective assessment of the quality of a report with respect to 17 specific desired learning outcomes, including the ABET A-K learning objectives.[18] For example, one of these learning outcomes is:

> Students will approach tasks involving the acquisition and interpretation of experimental results in a logical and systematic fashion. Specifically, students will make appropriate measurements, record information in a meaningful format, perform necessary analysis, and convey an interpretation of the results to an appropriate audience.

Table 4 provides four indicators of this ability (listed in the left hand column) and four levels at which a specific sample of student work could be judged with respect to each indicator. Newell, et al.[17] demonstrated excellent repeatability of the ratings assigned by different readers using these rubrics.

Of the 17 learning outcomes measured by the published rubrics, ten were identified as applicable to the energy audit project. Table 5 summarizes the performance for the Spring 2005 and Spring 2006 cohorts with respect to these ten learning outcomes. Each outcome was evaluated using 3-5 indicators and the scores represent the average values across all indicators for a given outcome.

The data show that the spring 2006 cohort's final reports were better in every respect than the spring 2005 cohort's, and for some objectives the difference was statistically significant to 95% confidence. Since the faculty team and course instruction were substantially identical these two semesters, it is likely that the improvement shown in Spring 2006 is attributable, or at least largely attributable, to the changes made in the Fall 2005 offering of Sophomore Engineering Clinic I.

Table 4: Rubric used for assessment of student reports with respect to the following outcome: "Students will approach tasks involving the acquisition and interpretation of experimental results in a logical and systematic fashion. Specifically, students will make appropriate measurements, record information in a meaningful format, perform necessary analysis, and convey an interpretation of the results to an appropriate audience."

Indicator	Score			
	4	3	2	1
Prepares a technical report with content appropriate to audience	Considers audience fully. Report is exactly geared to correct audience	Considers audience well, but may have a few moments of inappropriate level	Tries to consider audience but may over- or underestimate technical level	Gives little or no regard to the audience
Presents summarized results based on analysis of measurements	Provides clear, complete, correct, and concise analysis. Does not present uninterpreted data	Results are well summarized. Little or no uninterpreted data. Major points are covered. A few minor errors may occur.	Some interpretation and summary is made, but significant data is missing or left uninterpreted.	Students present data incorrectly with little or no interpretation.
Describes in appropriate detail the experimental procedures used	Procedures are clear and succinct.	Procedure is clear, but perhaps a bit short or wordy	Procedure is complete but difficulty to follow. Inappropriate detail level is presented	Procedure is incorrect or incomplete
Uses appropriate methods to estimate and interpret error	Present correct and detailed error analysis and explains its relevance	Presents correct error analysis but does not fully elaborate on its importance	Attempts to address errors but is lacking in procedure or consistency	Makes little or no effort to address experimental error

Table 5: Learning outcomes for Sophomore Engineering Clinic II, and mean performance of spring 2005 and spring 2006 cohorts with respect to each outcome (4=best, 1=worst).

Desired Outcome	2005	2006
Students demonstrate an ability to apply knowledge of mathematics, science, and engineering (ABET - A).	2.48	3.11
Students approach tasks involving the acquisition and interpretation of experimental results in a logical and systematic fashion. Specifically, students make appropriate measurements, record information in a meaningful format, perform necessary analysis, and convey an interpretation of the results to an appropriate audience.	2.19	2.60
Students design and conduct appropriate experiments that effectively use limited resources to obtain the necessary information.	**2.00**	**2.73**
Students demonstrate the ability to identify, formulate and solve engineering problems (ABET - E).	**2.31**	**2.90**
Students demonstrate understanding of contemporary issues relevant to the field of engineering (ABET - J). Students have an awareness of current technical material (journals, trade publications, web sites, etc.), develop an ability to find relevant current information and use this ability in their curricular assignments.	1.44	2.25
Students have the ability to use techniques, skills, and modern engineering tools necessary for engineering practice (ABET - K). Students apply fundamental principles of engineering to solve engineering problems.	2.17	2.83
Students have the ability to use techniques, skills, and modern engineering tools necessary for engineering practice (ABET - K)._ Students use the internet and appropriate software packages including spreadsheets, word processors, mathematical packages and process simulators to assist in problem solving.	2.22	2.83
Students have experience in undergraduate research.	**2.28**	**2.94**
Students have the broad education necessary to understand the impact of engineering solutions in a global/societal context (ABET - H). Students draw from their general education and science background to develop engineering solutions that demonstrate an awareness of energy, the environment, business and economics, government, and other global and societal issues.	2.11	2.50
Students demonstrate effective oral and written communication skills (ABET - G). Students will write effective documents including memos, e-mails, business letters, technical reports, operations manuals, and descriptions of systems, process, or components.	**2.04**	**2.83**
Number of Reports	9	12

Boldface indicates that the difference between 2005 and 2006 performance was statistically significant (95% confidence) for that outcome.

These same rubrics were applied to the final reports in Chemical Plant Design for the Spring 2007 and Spring 2008 semesters, when the Fall 2004 and Fall 2005 Sophomore Clinic cohorts were seniors. For this course, 16 different learning outcomes were determined to be applicable to the design project. While the specific plant design projects were different these two semesters, the courses were identical in most respects: the instructor and number and scope of deliverables were the same and the classroom instruction was substantially the same. Table 6 summarizes the results of the assessment.

Table 6: Outcomes for Chemical Plant Design, and mean performance of Spring 2007 and Spring 2008 cohorts with respect to each outcome (4=best, 1=worst).

Desired Outcome	2007	2008
Students demonstrate an ability to apply knowledge of mathematics, science, and engineering (ABET - A).	3.38	3.81
Students approach tasks involving the acquisition and interpretation of experimental results in a logical and systematic fashion. Specifically, students make appropriate measurements, record information in a meaningful format, perform necessary analysis, and convey an interpretation of the results to an appropriate audience.	3.06	3.38
Students design and conduct appropriate experiments that effectively use limited resources to obtain the necessary information.	3.5	3.75
Students possess a working knowledge of organic, inorganic, materials and physical chemistry.	3.81	3.88
Students possess a working knowledge of chemical engineering principles including balances, fluid mechanics, transport phenomena, separations, reaction engineering, unit operations, thermodynamics and process design.	3.31	3.56
Students demonstrate an ability to design a system, component, or process to meet desired needs (ABET – C). Students will select a component based on chemical engineering principles that is of an appropriate size and type to meet desired needs.	3.17	3.5
Students demonstrate an ability to design a system, component, or process to meet desired needs (ABET – C). Students will design a process or system, consisting of components, into operations that convert raw materials into desired products.	3.25	3.67
Students will have an ability to function on multidisciplinary and/or diverse teams.	3.375	3.5
Students demonstrate the ability to identify, formulate and solve engineering problems (ABET - E).	3.25	3.75
Students demonstrate understanding of contemporary issues relevant to the field of engineering (ABET - J). Students have an awareness of current technical material (journals, trade publications, web sites, etc.), develop an ability to find relevant current information and use this ability in their curricular assignments.	3.42	3.67
Students have the ability to use techniques, skills, and modern engineering tools necessary for engineering practice (ABET - K). Students apply fundamental principles of engineering to solve engineering problems.	3.69	3.88
Students have the ability to use techniques, skills, and modern engineering tools necessary for engineering practice (ABET - K)._ Students use the internet and appropriate software packages including spreadsheets, word processors, mathematical packages and process simulators to assist in problem solving.	3	3.45
Students have experience in undergraduate research.	3.3	3.8
Students have an understanding of professional and ethical responsibilities. (ABET – F) Students will take pride in the profession of chemical engineering and recognize their professional and ethical responsibilities.	3	3.13
Students have the broad education necessary to understand the impact of engineering solutions in a global/societal context (ABET - H). Students draw from their general education and science background to develop engineering solutions that demonstrate an awareness of energy, the environment, business and economics, government, and other global and societal issues.	3	3.5
Students demonstrate effective oral and written communication skills (ABET - G). Students will write effective documents including memos, e-mails, business letters, technical reports, operations manuals, and descriptions of systems, process, or components.	3.25	3.67
Mean Cumulative GPA	3.11	3.04
Number of Reports	4	4

Once again, the Spring 2008 Chemical Plant Design class out-performed the Spring 2007 Plant Design class in all respects. This was true despite the fact that the class of 2007 earned slightly better grades in the curriculum as a whole. While the Chemical Plant Design results were obtained from small sample sizes of 4 teams per cohort, and therefore not statistically significant, they provide an additional indication of a lasting impact from the Fall 2005 improvements to Sophomore Clinic I. Anecdotally, the Spring 2008 class projects was observed to show more evidence of divergent thinking than the Spring 2007 class. For example:

- The 2007 Plant Design project was on production of Methyl Methacrylate and the 2008 project was on synthesis of 1,3-Propanediol. In both cases, the problem statement referenced recent patents. The entire 2007 class designed reaction networks based upon data in the patent provided. In 2008, two teams did a more in-depth literature search, found a second recent patent on 1,3-Propanediol synthesis using a different catalyst, and performed a comparative assessment on which catalyst was more economical.
- Both the 2007 and the 2008 problem statements gave prices at which feedstock streams could be purchased. In 2008, one team designed a full process for synthesizing a reactant (ethylene oxide) on-site rather than purchasing it, and a second team's report showed evidence they had at least considered such an approach. In 2007, the final reports contained no evidence that any team considered any alternative scenario to purchasing reactants at the given prices.

Notably, the Fall 2005 Sophomore Clinic cohort achieved better outcomes than the previous cohort in both subsequent design courses, even with respect to outcomes such as "understanding of professional and ethical responsibilities" that are not addressed directly by Dym's model. One possible explanation for this observation is that the combination of exposure to Dym's model and the repetition gained from the series of design projects left the students better prepared to fully understand and approach design problems, and better able to write about them effectively.

Summary

Dym and co-authors[Error! Bookmark not defined.] noted that design problems are inherently unique and open-ended. Though there is no single "recipe" one can follow to solve a design problem, Dym et al. assert that there are repeatable and recognizable cognitive processes that are applicable to all design problems, and propose a cognitive model for the design process as an alternating series of divergent and convergent inquiries.

A previous paper[2] showed that integrating Dym's cognitive model into a sophomore engineering design course led to significant improvement in student approach and quality of final design products. This paper provides additional assessment data demonstrating that in subsequent design courses, students who had learned Dym's cognitive model continued to out-perform students who did not, even though Dym's model was not specifically referred to in those subsequent courses.

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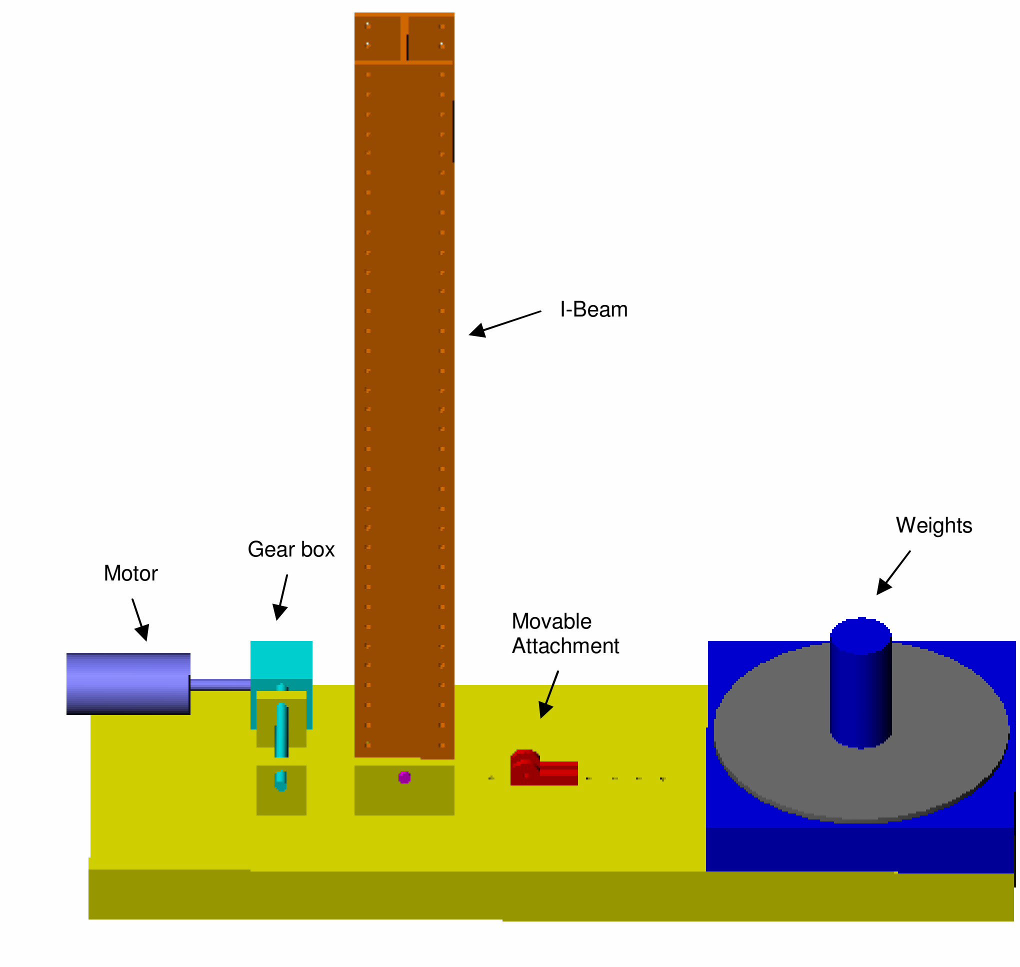

Figure 1: Substructure used by each team to support their crane.

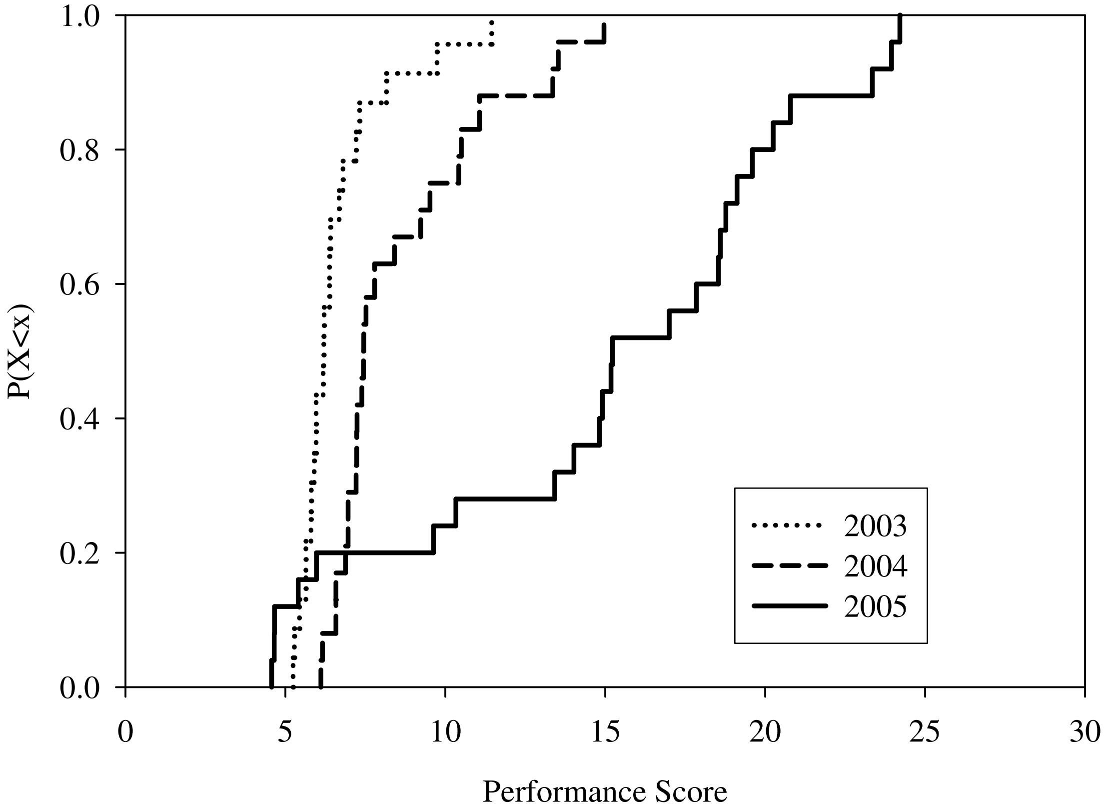

Figure 2: Comparison of performance scores for all teams in Fall 2003, 2004 and 2005 cohorts, using the 2003/2004 performance equation.

Bibliographical Information

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[1] Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D. and Leifer, L.J., “Engineering Design Thinking, Teaching and Learning,” *Journal of Engineering Education,* **95,** 1 (2005), accessible at http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=252.pdf

[2] K. Dahm, W. Riddell, R. Harvey, P. von Lockette E. Constans, J. Courtney, “The Converging-Diverging Approach to Design in the Sophomore Engineering Clinic,” *ASEE Annual Conference and Exposition*, June 2007, Honolulu, HI.

[3] Dally, J. W. and Zhang, G.M., “A Freshman Engineering Design Course,” *Journal of Engineering Education,* **83**, 2 (1994), accessible at http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=123.pdf

[4] Quinn, R. E., “Drexel’s E4 Program: A Different Professional Experience for Engineering Students and Faculty,” *Journal of Engineering Education,* **82,** 4 (1993), accessible at http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=84.pdf

[5] Froyd, J. E. and Ohland, M. W., “Integrated Engineering Curricula,” *Journal of Engineering Education,* **94,** 1 (2005), accessible at http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=246.pdf

[6] D. K. Ludlow and K. H. Schulz, "Writing across the chemical engineering curriculum at the University of North Dakota," *Journal of Engineering Education*, vol. 83, pp. 161, 1994, accessible at http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=547.pdf

[7] J. A. Newell, D. K. Ludlow, and S. P. K. Sternberg, "Progressive development of oral and written communication skills across and integrated laboratory sequence," *Chemical Engineering Education*, vol. 31, pp. 116-119, 1997.

[8] N. Van Orden, "Is writing an effective way to learn chemical concepts?," *Journal of Chemical Education*, vol. 67, pp. 583, 1990.

[9] E. Constans, J. Courtney, K. Dahm, J. Everett, C. Gabler, R. Harvey, L. Head, D. Hutto, H. Zhang, “Setting the Multidisciplinary Scene: Engineering Design and Communication in the ‘Hoistinator’ Project”, *ASEE Annual Conference and Exposition*, June 2005, Portland, OR, accessible at http://papers.asee.org/conferences/paper-view.cfm?id=21514

[10] http://www.pre.nl/eco-it/default.htm, accessed December 5, 2008.

[11] Von Lockette, P., Riddell, W., Dahm, K., Harvey, R., Courtney, J., Pietrucha, B., Diao, C., Accini, D., “Bottle Rockets and Parametric Design in a Converging-Diverging Design Strategy,” *Proceedings of the ASEE Annual Conference and Exposition,* June 2006, Chicago, IL, accessible at http://papers.asee.org/conferences/paper-view.cfm?id=699

[12] http://www.schemmscience.com/physics/labs/sodabottlerox.pdf, accessed Jan. 3, 2007

[13] http://hometown.aol.com/hayhurst1/h2orocket.htm, accessed Jan. 3, 2007.

[14] http://www.grc.nasa.gov/WWW/K-12/VirtualAero/BottleRocket/educator.htm, accessed Jan. 3, 2007.

[15] Riddell, W.T., Jansson, P.M. and Law, R.J., “Measurement and Conservation of Energy Use in Campus Buildings,” *Proceedings of the ASEE Mid-Atlantic Conference,* Fall 2004.

[16] Riddell, W. T., Jansson, P.M., Dahm, K.D., Benavidez, H.S., Haynes, J., and Schowalter, D., “Conservation of Energy for Campus Buildings: Design, Communication and Environmentalism through Project Based Learning,” *ASEE Annual Conference and Exposition,* June 2006, Chicago, IL, accessible at http://papers.asee.org/conferences/paper-view.cfm?id=355

[17] J. A. Newell, H. Newell, and K. D. Dahm, “Rubric Development and Inter-Rater Reliability Issues in Assessing Learning Outcomes,” *Chemical Engineering Education*, 36, 3 (2002).

[18] Engineering Accreditation Commission, *Engineering Criteria 2000,* Accreditation Board for Engineering and Technology, Inc., Baltimore, MD, 1998.