AC 2009-1636: DESIGN PROCESS LEARNING AND CREATIVE PROCESSING ABILITY: IS THERE A SYNERGY?

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Design Process Learning and Creative Processing Ability: Is there a synergy?

Abstract

We present a study where we have analyzed the change of design process knowledge and creative processing skills in our engineering students. Overall, our findings indicate that while our students significantly improve their design processing knowledge during sophomore, and junior years of their engineering education, in the senior year, what had been gained is possibly being lost. Likewise, while there is an increase in creative processing skills in the sophomore year, for junior and senior years, what is gained is lost. As a result, senior students may be leaving the university with less design processing knowledge and creative processing abilities than they had while they were sophomores. We believe that our study can be a foundational reference for researchers and educators who aim to increase our graduates' creative design outcomes.

Introduction

Design learning and the related design ability have a three-pronged foundation: 1) design process knowledge, 2) design analysis knowledge, and 3) creative processing ability (ideation). Design process knowledge, in general, is taught in first year design courses, and then practiced during capstone design. During second and third year courses, the engineering curriculum focuses on analytical concepts and techniques ultimately intended to support design analysis ability. However, students frequently have difficulty in integrating their design process knowledge and analysis abilities during capstone design projects.

Most four year engineering programs include a first year course focused on the engineering design process where students are exposed to the wide range of issues that must be considered with regard to the 'real life' activity of designing a product or a process. These courses typically culminate in a team report describing the breadth of information accumulated and considered to arrive at the final recommended design. However, at the first year, students normally lack the knowledge to perform any meaningful analysis on their product or process, but rather focus their activities on the less 'technical' but equally important aspects of the design, such as consumer needs, economic impact, safety and design communication.

Once students leave their first year, the curriculum focus usually turns almost exclusively to teaching the analytical tools students will need as working engineers to accomplish innovative design, with far less emphasis on the broad design issues that extend beyond the analysis. Anecdotal evidence shows that students do not connect the newly acquired analytical knowledge with the design process, creating a design learning gap. When students return to a design emphasis in the senior year capstone course, they are expected to bridge this gap by synthesizing the broad engineering design understanding from the first year with their analytical depth gained in the second and third years to produce unique engineering design solutions. Given the anecdotal evidence indicating difficulty in this integration, we find it important to assess how the student design process knowledge changes over the course of the four years they spend in engineering programs.

As indicated above, we treat design learning and the related design ability to have a three-pronged foundation: 1) design process knowledge, 2) design analysis knowledge, and 3) creative processing ability. Perhaps, one could assess the level of analysis knowledge using course grades of technical courses (e.g., engineering mechanics, thermodynamics, etc.), yet assessment of creative processing capability requires specific instruments, which are beyond what students come across in their curriculum normally. It is very important to know, however, how the creative processing ability of students changes over the course of the four years they spend in engineering programs. While we are not prepared to make certain attribution to its cause, once again, we have anecdotal evidence suggesting that students become less creative as they progress in their engineering education.

What might perhaps be more significant is what happens at the cross-roads of these two issues: How does design process knowledge change overtime for engineering students? How does creative processing ability change overtime for our engineering students? We believe changes in these two dimensions have implications for design outcomes of our graduates, especially given the increasing significance of innovation in the technical domains. Below we provide the background for our study followed by information on instruments, participants and results.

Background

In the past 20 years, much interest and effort has been directed toward increasing the design emphasis and adding related curriculum components in undergraduate engineering education. At most institutions in the US this effort has focused primarily on first year (cornerstone) and senior year (capstone) design courses. As stated by Dym[1], there is hard evidence that supports the "strong belief that first-year, cornerstone courses:

- enhance student interest in engineering;
- enhance student retention in engineering programs;
- motivate learning in upper division engineering science courses; and
- enhance performance in capstone design courses and experiences."

At this time, however, the emphasis in the second and third years has remained primarily on engineering science and analysis[1]. This begs the question, if adding design experience in the first and last years of traditional engineering curriculum has had such a positive effect, could the design knowledge, interest, and motivation of our students be further enhanced by incorporating design experiences into the second and third years as well? A few engineering programs have taken major steps to incorporate significant design experiences throughout all years of undergraduate study (e.g., Harvey Mudd College [2]), but this seems to be the exception, not the rule.

Design is also seen as providing the context for our students to practice their creative processing ability. Indeed, industrial and academic leaders long expressed concerns about the impact of traditional engineering education on the creative potential of future engineers. A lack of creativity is viewed as problematic in a rapidly changing technology-oriented world where generating new ideas is essential to survival [3,4]. Industry has also perceived new BS engineering graduates as lacking design capability or creativity, as well as an appreciation for considering alternatives. In the past several years, universities have responded to these challenges by adding more design content and introducing more open-ended design problems into their engineering curricula. As Liu and Schonwetter put it: "Since creativity emanates from problems, it seems more natural for engineering students to gain creativity through practice of problem solving." [5] Articles discussing the guarded success of these initiatives have appeared in various academic journals over the last 10 years. Yet the need to increase the design and creative processing ability of our students still persists.

Our research effort funded by Penn State University's Leonhard Center set out to investigate the change in the design process knowledge by capturing a current snapshot of design learning in Penn State engineering students across all four years. But consultations with several experts who have backgrounds in engineering design and psychology brought up some interesting questions about the difference between possessing design knowledge and applying it. Even if our students possess the knowledge, are they able to apply it to create new, novel and innovative designs? And are they in an environment that motivates them to do so? The additional questions indicated that design learning should not be investigated in isolation, but rather should be studied in conjunction with creative processing ability and climate. Accordingly, in this paper, we present a study where we have attempted to measure the change of design process knowledge and creative processing skills in our engineering students. We believe that our study can be a foundational reference for researchers and educators who aim to increase our graduates' creative design outcomes by offering one possible set of measures that could be used to document changes after new initiatives are implemented.

Study Design and Data Collection

During the fall 2007 semester, baseline data related to design process knowledge and creative processing ability was collected from students across all four years and several engineering disciplines using the Comprehensive Assessment of Design Engineering Knowledge (CADEK) [6] instrument, a divergent thinking measure, and a creative climate survey. While this baseline data was collected simply to serve as a benchmark for comparison for future curricular innovations, it also provides an interesting window into the current state of both creative processing ability as well as overall creative climate. While results from a preliminary analysis of a small representative sample of data were discussed in an earlier paper, this paper reports on the findings of the full data collection.

The CADEK instrument was developed in spring 2005. Tests during the spring 2005 and fall 2006 semesters showed that the instrument successfully measured overall changes in design process knowledge and skills using 20 questions related to the engineering design process, working in teams, and design communication [7]. This instrument was also used to identify where in the curriculum students obtained their design process knowledge as it asks students to identify one or more courses in which they learned the content needed to answer each individual question.

Two significant modifications were made to the original CADEK instrument for the purposes of this study. First, during the pilot phase, the questions were modified to allow students to identify any course as the source for their design learning, not just the first year cornerstone course. After each CADEK question, students were also asked to evaluate their agreement with two statements; “I have acquired related knowledge to this question during the design class I have just completed” and “Any person who takes this course should be able to answer this question.” Responses were coded as follows: “agreed” = 3, “neutral” = 2, and “disagree” = 1. These results suggested that students perceived most items to be an adequate reflection of the material covered in their introductory engineering design course. Based on these ratings along with student comments, one question was removed from the CADEK. With this change, the instrument was published in 2007. [7]

Second, due to the large number of students involved, several questions (particularly those measuring knowledge of design communication), were changed from open ended sketches to multiple choice to allow for electronic administration. However none of the questions were changed significantly beyond slight wording changes for clarity, a re-evaluation of the CADEK was unnecessary.

At the end of the fall 2007 semester, this slightly modified CADEK was administered in several undergraduate engineering classes to asses design process knowledge. In an attempt to assess design process knowledge differences at all stages of undergraduate engineering education, rather than simply measuring the difference between the cornerstone and capstone experience, data was collected in second and third year courses as well to gain a more complete picture of what is happening with student’s design knowledge throughout the undergraduate engineering educational experience.

The CADEK answers were analyzed by a graduate student using a detailed evaluation rubric. For multiple-choice questions, 10 points were awarded for each correct answer and 0 points were awarded for each incorrect answer. However, the majority of the questions in the CADEK are open-ended, hence scoring them required a well-defined rubric. The evaluation rubric used for this study was developed from an analysis of typical student responses collected during the CADEK pilot testing.

Although creative performance has many influencing factors, data collection for this study focused on measuring divergent thinking and creative climate. To assess the divergent thinking of the students, a subscale of Torrance Test of Creative Thinking (TTCT) was used.[8] Specifically, the Unusual Uses Task was used which asks participants to generate as many unusual uses as they can for a tin can in a ten-minute period. The measure was scored for originality and fluency (i.e., number of ideas generated). The TTCT is the most widely used measure of divergent thinking ability. [9]

To assess the students’ perceptions of the creative environment, a creative climate measure was given. The measure was derived from the work of Hunter and colleagues. [10, 11] The 54-item measure is comprised of five factors: 1) work freedom and stimulation, 2) positive peer group and exchange, 3) instructor direction and influence, 4) organizational capacity and support (internal) and 5) organizational integration and extension (external). These factors may be viewed separately as unique dimensions or aggregated to represent a general creative climate factor, the choice made for these analyses. Internal consistency for the measure is .91.

The baseline pilot data aimed to answer the following questions:

1) Is design process knowledge changing as students progress from their first to their last year as an undergraduate engineering student?
2) Is creative climate and divergent thinking ability also changing during this time? And if so, how?

Participants

Data sets were collected from 367 engineering students; 19 first and second year students in freshman level EDSGN 100 (Introduction in Engineering Design), 256 first through fourth year students in sophomore level E MCH 011 (Statics), 1 third year student in M E 340 (Mechanical Engineering Design Methodology), 87 third and forth year students in junior level C E 340 (Design of Concrete Structures), and 4 senior students in M E 440W (Senior Capstone Design Course).

Results and Conclusions

The full data set ($N = 367$) indicates an interesting trend to changes in design knowledge across the four years (Figure 1). Freshman ($M = 4.93$, $SE = .31$), Sophomores ($M = 5.95$, $SE = .36$), Juniors ($M = 5.92$, .14), and Seniors ($M = 5.03$, $SE = .32$). The largest sample size was collected from the Statics course which primarily consists of sophomores, but includes students from the whole range of years. Overall, our CADEK results indicate that while our students significantly improve their design processing knowledge during sophomore, and junior years of their engineering education, in the senior year, what is gained is lost. However, in comparison to other class years, our senior student N was very small, and hence we cannot generalize this result, and we plan to collect additional data.

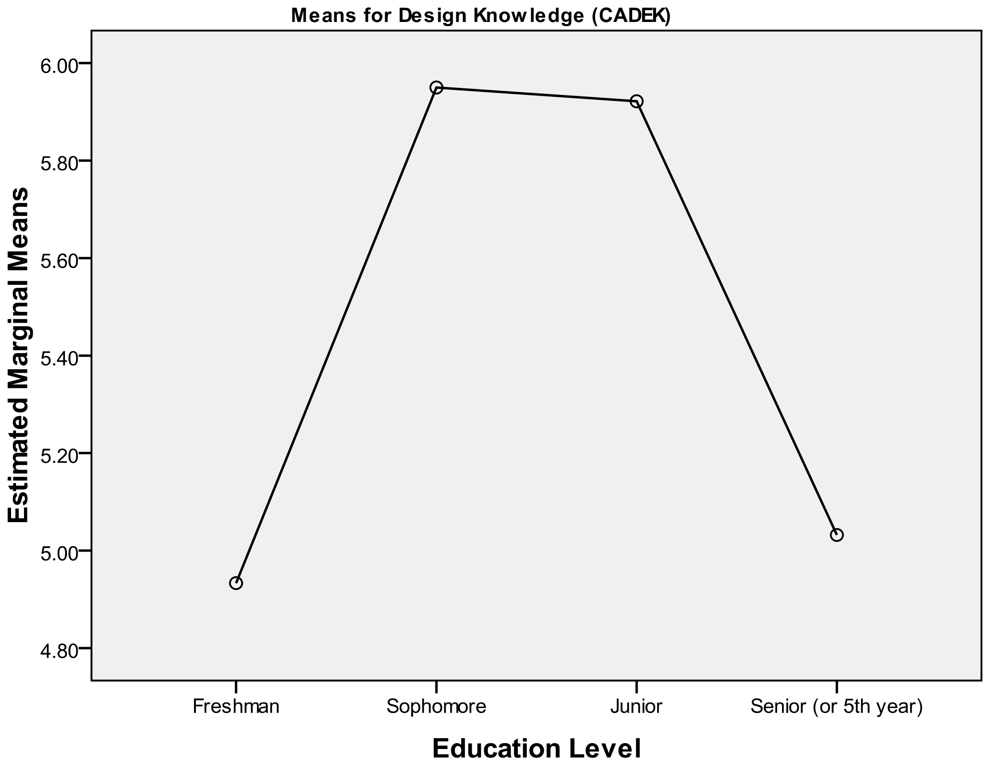

Figure 1. Mean CADEK Trend Across Four Academic Years

In comparison, the results of the creativity measures indicate that although students appear to be gaining in design process knowledge (except the senior year), they do not perceive their environment to be more supportive of creative thinking as they move through their academic careers. In fact, results from an ANOVA analysis (F (3, 359) = 3.72; p =.012) suggest that students view their environment as *decreasingly* supportive of innovation over their four years at Penn State. Note Figure 2, for example, which depicts the general decrease in perceived support for innovation. It should be acknowledged that there is a slight increase in perceived support in the junior year sample when considering the main effects of academic year only. However, closer inspection of the significant interaction between courses and educational year (F(3, 359) = 4.302, p = .014) reveals that when courses are considered, the trend downwards in support across academic years is even more dramatic (Figure 5). Thus, within this sample it appears that students view the creative climate to be less supportive of creative thinking as we move across academic years; a downward trend that is stronger in some classroom cohorts than others.

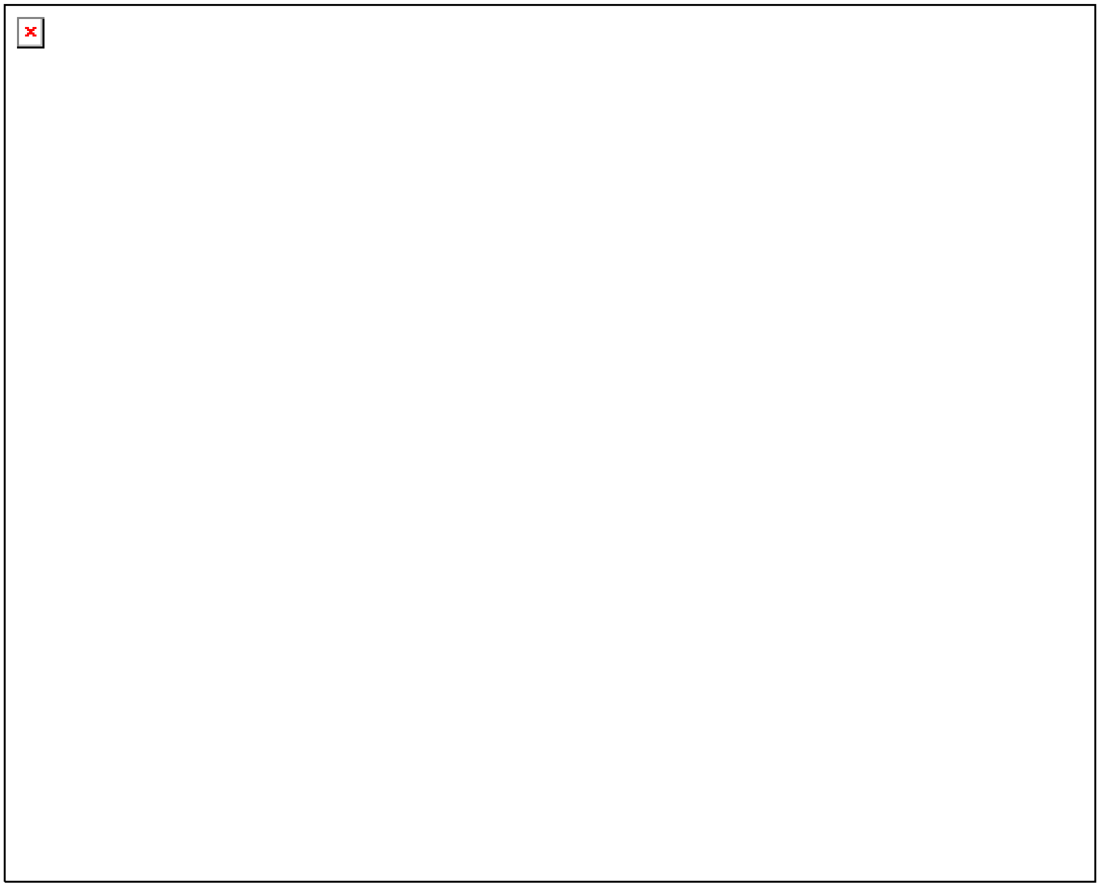

Figure 2. Mean Differences for "Creative Climate Total when considering both education level and course"

In addition, results from the divergent thinking measure suggest that the originality and flexibility of ideas generated decreases over the four years as well. Although statistically insignificant, these trends appear noteworthy (Figures 3 and 4). Thus, taken in conjunction these results suggest that an understanding of design learning involves not only the obtainment of design process knowledge but also the environment in which this knowledge may be applied. It appears critical that future studies explore this complex relationship further.

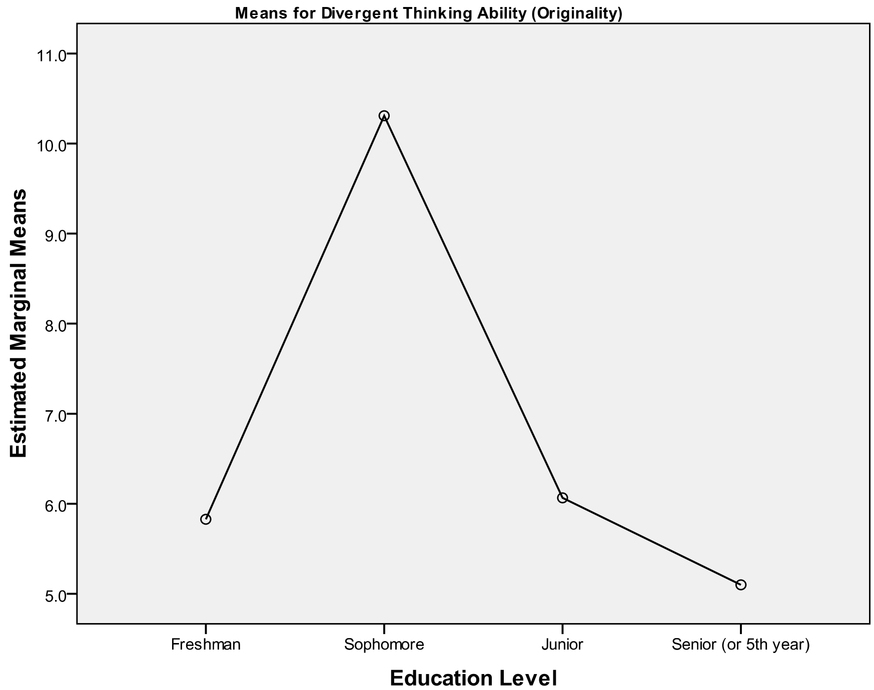

Figure 3. Mean Trends for the Number of Highly Original Ideas Generated in a Ten-minute Period

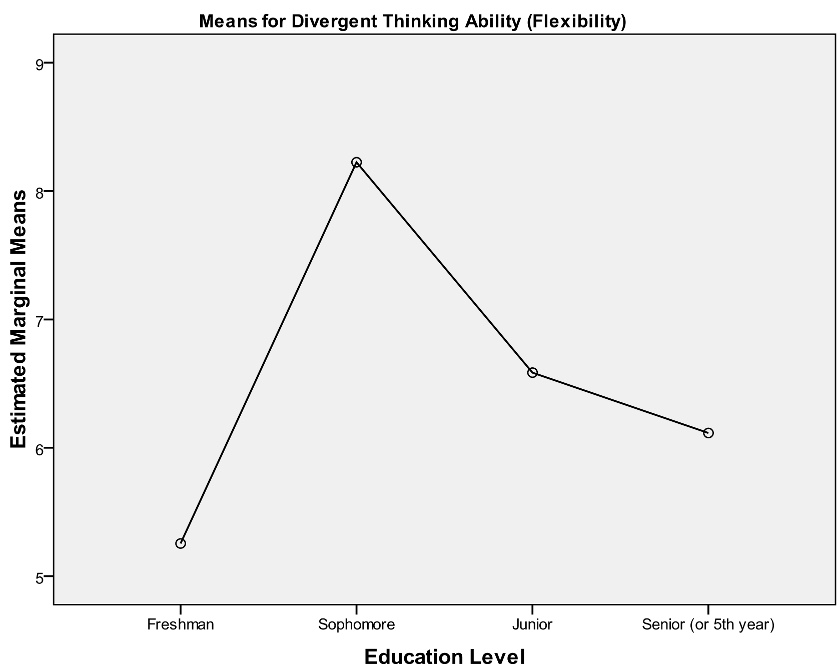

Figure 4. Mean Trends for the Flexibility (i.e., number) of Unique Categories of Ideas Generated in a Ten-minute Period

Overall, our findings indicate that while our students significantly improve their design processing knowledge during sophomore, and junior years of their engineering education, in the senior year, what is gained may be lost. Likewise, while there is an increase in creative processing skills in the sophomore year, for junior and senior years, what is gained is lost. As a result, senior students may be leaving the university with less design processing knowledge and creative processing abilities than previously they had when they were sophomores. This situation of increasing design knowledge (except perhaps the senior year) but considerably decreasing originality and fluency of ideas generated in fact resonates with many. Industry has perceived new BS engineering graduates as lacking design capability or creativity, as well as an appreciation for considering alternatives. Further, a 1995 ASME report ranked *creative thinking* as 5th of 56 top desired "best practices" for new BS-level engineers as seen by industry and academe.[12] In the past several years, universities have responded to these challenges by adding more design content and introducing more open-ended design problems into their engineering curricula. Articles discussing the guarded success of these initiatives have appeared in journals. Yet the need to increase the creative potential of graduates still persists.[13] In fact, our preliminary results confirm this.

Recognizing that other factors play a role as well, studies have documented (1) that people whose personality types indicate high levels of creative potential are leaving engineering at higher rates than the student body average and (2) faculty teaching methods lean heavily towards a 'plug-and-chug' approach to engineering problem solving, stifling creativity.[14] Indeed, one of the earliest accounts of this is by A.D. Moore [15] – an engineering professor - : "**I wish I could say that these educational areas [science and engineering] also have, as a main purpose, the stimulation of your creativity, and that they succeed in doing it. I am afraid that neither is true. In fact, I suspect that the taking of a degree in engineering or science may, in many cases, do more to stifle creativity than to stimulate it**."

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