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Linking First-Year and Senior Engineering Design Teams: Engaging Early Academic Career Students in Engineering Design

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ABSTRACT

In Biosystems Engineering at Oklahoma State University, senior design is a two semester course in which students work on real-world projects provided by clients. First-year (freshmen and transfer) students enroll in an introductory engineering course. Historically, these students worked on a team-based analysis project, and the engineering design process was discussed but not explicitly applied. This study investigated the hypothesis that first-year and senior design teams can be linked through capstone projects to more effectively introduce design. First-year students design a small portion of the client-based capstone project as identified by and supervised by the seniors. Several assessment tools were used: student knowledge of the design process, presentations and student surveys. More than 90% of introductory students agreed that the project was worthwhile and helped them learn about engineering as a future career. After having institutionalized the linkage, seniors were more likely to identify appropriate projects and viewed the mentoring as beneficial.

Key Words: Engineering design, introduction to engineering, capstone, senior design

BACKGROUND

Previous engineering education research has indicated the importance of teaching the engineering design process to first-year students (Sheppard & Jenison, 1997; Dym, 1999; Burton & White, 1999; Jacobson et al., 2006; Vallim et al., 2006). Engineering programs have attempted several strategies at teaching engineering design concepts in first-year courses, and these strategies are typically based on projects (Dally & Zhang, 1992) or individual laboratory exercises (Schubert et al., 2012). Burton and White (1999) classified course models for first-year engineering design. Identified models included the following: (i) reverse engineering to dissect a common item and analyze and discuss its components, (ii) creating something useful by designing and testing an item to complete a task, (iii) full-scale project involving semester-long project to build a model or prototype, (iv) small-scale project that involves assembly and testing of an object that meets certain specifications, (v) case studies where the class focuses on discussion and analysis techniques to teach design concepts from actual engineering projects and/or failures, (vi) competition method where student teams compete to build a specific device, (vii) non-profit project where real world problems are brought into the classroom, and (viii) redesign a local project where teams analyze components of a larger engineering project.

Some of these methods specifically focus on the idea that first-year students are rarely challenged to engage their creativity in solving real-world problems with real-world clients. However, the effort expended to identify real-world projects with actual clients is fairly extensive. On the other hand, engineering programs across the United States are required as part of their accreditation through ABET to include a senior design course. The curriculum must " . . . culminate in a major design experience based on knowledge and skills acquired in earlier course work and the projects must incorporate appropriate engineering standards and realistic constraints" (ABET, 2007).

In Biosystems Engineering at Oklahoma State University (OSU), the senior-design course is a two-semester sequence (BAE 4012/BAE 4023). Students work on real-world projects provided by industry clients (Fox et al., 2011). The course includes idea generation, patent and standard research, and selection of a final design from alternative solutions in the fall semester, followed by design specification, prototype development, and construction in the spring semester. First-year students in Biosystems Engineering at OSU enroll in an Introduction to Biosystems Engineering course (BAE 1012), a two-credit hour course that includes a lecture and two computer laboratory sections. The lecture component of BAE 1012 covers academic skills, the transition from high school to college, an introduction to engineering, an introduction to Biosystems Engineering, how to become a professional engineer, the engineer design process, personality types, and how to work in teams. Historically during the laboratory sessions, students were divided into teams and worked on a semester-long data analysis project with a faculty member in the department. Faculty would propose data analysis projects that were based on or corresponded with some aspect of their research program. Therefore, the data analysis projects were largely research-oriented rather than emphasizing critical aspects of engineering design. The engineering design process was typically discussed but not explicitly applied in the course at the scale of a semester-long project.

Our hypothesis is that first-year (BAE 1012) and senior design (BAE 4012) engineering teams can be linked through real-world senior-design capstone projects to more effectively introduce engineering design principles to the early academic career students. Atman et al. (1999) compared engineering design at the first-year and senior levels, but did not consider the impact of linking design teams. Most first-year engineering students lack many of the engineering science and fundamental courses required for a detailed design, but can assist in terms of the development of innovative conceptual design solutions. Ideally first-year engineering students (i.e., subcontractor) will design a small portion of the senior design project as defined by and supervised by the senior design teams (i.e., contractor), providing them with a context upon which to build their engineering knowledge (Kilgore et al., 2007). Students will be provided with a framework upon which to lay the core mathematical and scientific skills that they are learning in their other courses. As a result of linking first-year and senior engineering teams, early academic career engineering students will be able to effectively decide on whether engineering, and more specifically Biosystems Engineering, is an appropriate career path. Courter et al. (1998) specifically noted the advantage of problem-based first-year engineering projects in providing a context for making career decisions. Furthermore, first-year engineering students will be given greater opportunities to form mentoring relationships with senior students in engineering (Meyers et al., 2010).

BAE 1012 AND SENIOR DESIGN TEAM LINKAGE AND APPLICATION

In the Fall 2012 and Fall 2013 semesters, senior design teams were formed in September and client meetings relative to their projects occurred shortly thereafter. BAE 1012 teams were formed at the beginning of October, after introducing and discussing the engineering design process on a small-scale project. Initial team meetings were held in the laboratory sessions of BAE 1012 in early October with at least one senior design team member attending this first meeting. Future meetings between the groups were determined by the teams outside of class.

The senior design teams were made responsible, with some guidance from the instructors of the BAE 1012 and BAE 4012 courses, on the extent of the design projects for the first-year students. BAE 1012 students were required to submit progress memorandums at the end of October and the middle of November. At the end of the semester, BAE 1012 students then presented their design-based projects in an open poster session to the department during the final exam for the course. Five-point quantitative rubrics were used to evaluate the poster presentations as discussed below. The BAE 1012 and senior design students were then surveyed at the end of the semester. The first-year students were surveyed during their final poster presentations resulting in 100% participation in the survey; the senior design students were surveyed at a course time after their fall final design presentations which resulted in less than full participation in the surveys.

In the fall semester of 2012, enrollment in senior design was 36 students. Twelve senior design teams were formed consisting of three students per team. With an enrollment of 40, twelve corresponding teams were formed in BAE 1012 with teams of three to four students. During the fall semester of 2013, only 28 students were enrolled in senior design; therefore seven design projects were formed with four students per team. Enrollment in BAE 1012 was 32; therefore, one of the senior design project teams agreed to mentor two BAE 1012 teams. The BAE 1012 students were divided into eight groups with three to five students per team. A summary of the senior design project titles and the corresponding BAE 1012 project team titles are shown in Table 1.

ASSESSMENT

Three primary metric goals were identified to assess the BAE 1012/BAE 4012 linkage. These metric goals and the corresponding assessment tools utilized to evaluate the linkage are outlined below:

Metric Goal: First-year engineering students in BAE 1012 can identify, apply, and discuss the steps of the engineering design process.

> *Assessment Tool:* Through a designated poster presentation on their projects, first-year students were able to discuss the application of the steps of the engineering design process in a poster presentation to faculty, staff, graduate students, and other undergraduate students. Ratings of the posters by faculty members in the department were based on a five-point quantitative rubric (1 – Unsatisfactory, 3 – Developing, and 5 – Exemplary) on the following criteria related to this metric goal: (i) plans, prepares and delivers a well-organized, logical, poster presentation, (ii) develops an appropriate, clearly stated problem statement for the design/analysis problem, and (iii) design achievement. Also, student performance was assessed before and after the semester-long project on in-class quizzes related to a question documenting the steps of the engineering design process.

Metric Goal: First-year engineering students in BAE 1012 (i) view the design projects as worthwhile, (ii) understand what it means to be an engineer, and (iii) are able to make an early decision regarding their desires to pursue a Biosystems Engineering degree.

> *Assessment Tool:* Students were asked to complete a four point qualitative survey (1 – strongly disagree, 2 – disagree, 3 – agree, and 4 – strongly agree) on (i) whether the design projects

BAE 4012	BAE 1012	BAE 1012 Project was the Entire or a Subset of Senior Project
Fall 2012		
Design above ground storm shelter meeting FEMA and other certifications	Storm Shelter Design	Entire
Concept to rotate large square bales 90 degrees when ejected from baler	Large Square Bale Quarter Turn Attachment	Entire
Design of a plastic bag uncuffer for cardboard packing boxes	Automated machine for pulling plastic around a box	Subset
Design mechanism to fold round HDPE pipe into a U-shaped cross section	Crimping polyethylene pipe for a more cost efficient geothermal energy project	Entire
Develop design(s) for an environmentally friendly "green" parking lot	Impact of Drained Freeze-Thaw on Pervious Concrete Strength	Subset
Design to solve current problems with trailer sidewall welding jigs	New jig system for welding trailers	Subset
Optimize augers used to meter proppant into mixing tub	Increase the output efficiency of sand auger on Halliburton's FB4K mobile blender	Entire
Determine the best method to check "total indicator of run out" (TIR) on sucker rods	Comparison of LVDT versus CCD for measuring sucker rods	Subset
Low power water filtration using hollow fiber ultrafiltration membranes	Using UV Light Radiation to Eliminate Microorganisms from Filtered Water	Subset
Dissolved iron pretreatment for a reverse osmosis water purification system	Simple, low-cost, and efficient iron removal mechanism	Subset
Develop an improved mixing system for coffee bean cooling	Redesign the paddle system of the cooling bin	Subset
Mechanized rock drilling addition to a manual water well drilling system	Design of Mobile Water Well Drill Mount	Entire
Fall 2013		
Design of a 300 kg roaster by modifying current smaller coffee roaster design	Design of the Fire Box for High Temperatures	Subset
Treatment for flammable liquids in a fire safety retention pond	Coagulation of Flammable Liquids at Fire Service Training Facility	Subset
Gleaner distribution auger test system to determine efficiency of distribution augers in the grain cleaning process	Conveyor system that will distribute material into the hopper at a constant rate	Entire
Mechanical advantage pump jack accessible by handicap and young children	Design of the gear system for a mechanical pump jack	Subset
Irrigation hand pump for larger scale irrigation to farms of developing communities	Design of a base for an irrigation hand pump	Subset
Alum Microfloc system to continuously decrease phosphorus concentration entering a cove of Lake Wister	Water treatment system that distributes alum into the lake water	Subset
Alum Microfloc system to continuously decrease phosphorus concentration entering a cove of Lake Wister	Design of a microfloc curtain	Subset
Design and cost effective storm shelter	Design of a tornado shelter door	Subset

Table 1. Senior design (BAE 4012) and Introduction to Biosystems Engineering (BAE 1012) project descriptions.

were worthwhile, (ii) whether the design project helped them to increase their understanding of engineering, and (iii) whether the design project and interaction with senior design students helped them to make an informed decision regarding the suitability of the Biosystems Engineering degree for their future academic and professional careers.

Metric Goal: Senior engineering students are engaged with the first-year design teams, providing a collaborative working environment upon which everyone benefits, and view the linked projects as beneficial for completing their two-semester senior design project.

Assessment Tool: At the end of the semester, seniors complete a four point qualitative survey (1 – strongly disagree, 2 – disagree, 3 – agree, and 4 – strongly agree) of their experiences with the first-year design teams including ranking of the benefit of the linked projects for the BAE 1012 students teams and for their senior design teams. The senior design students were asked explicitly whether the team linkage should occur in the future using the same four point survey scale. The senior design students were also asked to explicitly state positive and negative aspects of the program.

Statistical Tests

Cumulative poster evaluation scores from the past four years were separated into two groups: (i) Fall 2010 and Fall 2011 with research-based projects and (ii) Fall 2012 and Fall 2013 with design-based projects. The Fall 2010 and Fall 2011 semesters included 15 and 16 projects, respectively. These groups were statistically compared using t-tests to determine if statistical differences existed between the groups.

The survey response from the four-point qualitative rubric is an ordinal or interval variable, a type of categorical data where there is an ordering of the responses for the variable. Responses were separated by year (Fall 2012 and Fall 2013) and the medians compared for significant differences using a Mann-Whitney rank sum test (SigmaStat, v12.5). A nonparametric procedure was used because the responses were not normally distributed nor possessed an equal variance.

PROJECT EVALUATION RESULTS AND IN-CLASS PERFORMANCE

Compared to earlier research-based projects, results of the design-based BAE 1012 poster evaluations were consistent over the past four years (Table 2). When separated into groups of research-based projects (Fall 2010 and 2011) and design-based projects (Fall 2012 and Fall 2013), statistical

Research-Based Projects			Design-Based Projects		
	μ*	σ*		μ	σ
Fall 2010 (n = 15)	77.6%	2.8%	Fall 2012 (n = 12)	82.7%	5.7%
Fall 2011 (n = 16)	88.4%	4.3%	Fall 2013 (n = 8)	81.2%	7.6%

* μ = average and σ = standard deviation.

Table 2. Statistics from faculty evaluations of BAE 1012 student project teams on poster presentations of their design projects.

tests suggested no significant difference between the groups relative to the poster evaluations (p value = 0.57). While performance did not statistically improve or decline with the switch to more design-based projects, comments from poster evaluators clearly indicated that the students presenting design-based projects were more engaged in their projects, better understood the projects' backgrounds, and more confidently presented their posters.

As noted earlier, in the previous research-based projects, the engineering design process was simply introduced. Students were asked a quiz question requiring them to place the steps of the engineering design process in the correct order. However, there was limited application of the process as the course transitioned to data analysis. When moving to the design-based projects, there were greater opportunities to introduce and apply the process. After introducing the design process, applying the process for a small-scale hypothetical design scenario, and before the semester projects started, introductory students across the two years averaged 66% on a question requiring students to indicate the correct order when given a list of the steps. This question was part of an isolated quiz during the semester. After the semester design project and preparing a poster outlining the steps of their design project, students averaged 80% on a similar question but this time requiring them to list the steps in the correct order. This question was part of a cumulative quiz at the end of the semester. Even though assessment data were not available on an end of the semester question on the design process under the research-based model, students exhibited increased knowledge of the engineering design process when exposed to the design-based and real-world projects.

BAE 1012 Survey Results

Survey results of the BAE 1012 students consistently suggested that the design-based projects were worthwhile (Fig. 1). In the past two years, 70 of 72 students (97.2%) agreed or strongly agreed that the design project was worthwhile. Even more important was that the design project helped these first-year students learn more about engineering and the engineering design

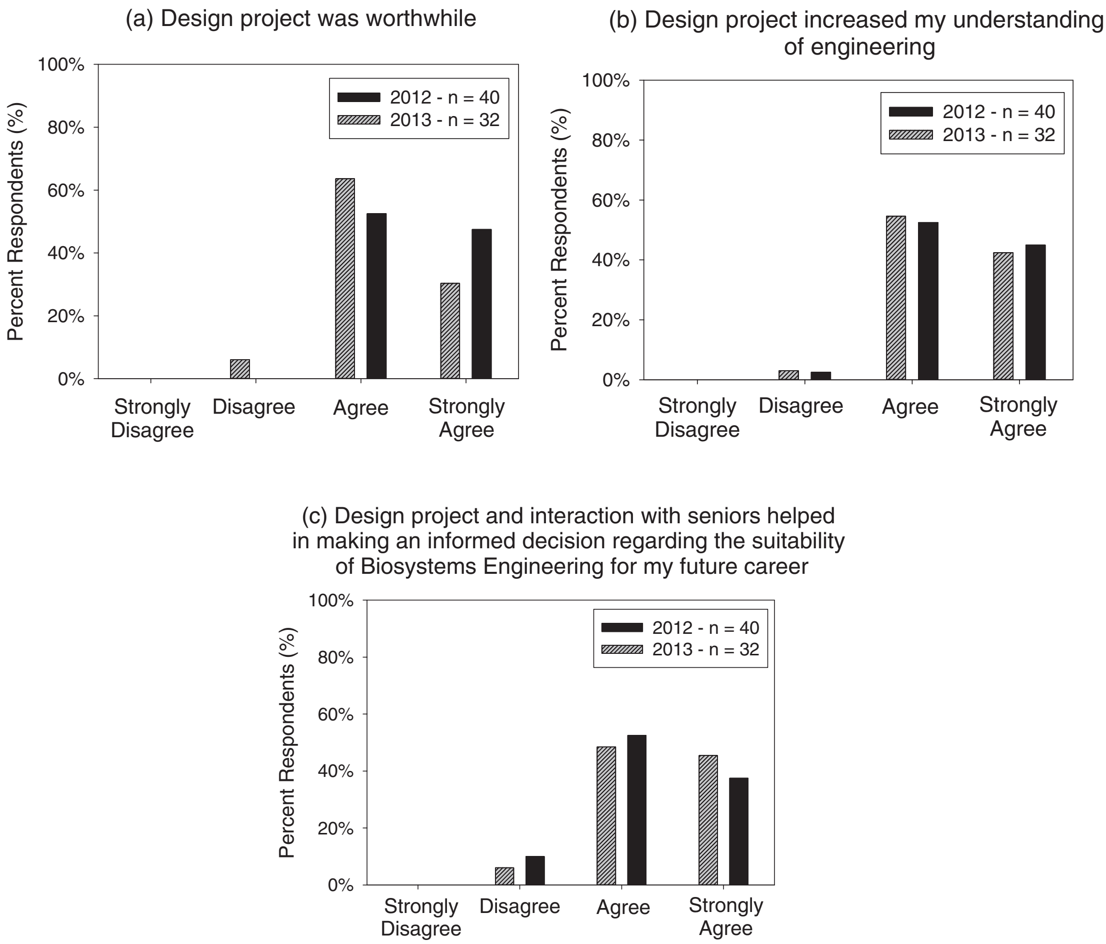

Figure 1. Results from the surveys of first-year (freshmen and transfer) students enrolled in BAE 1012 in 2012 and 2013 regarding the linked projects.

process. Again 70 of 72 students (97.2%) agreed or strongly agreed that the design project increased their understanding of engineering. A step further was that the design projects and interaction with the seniors consistently helped the BAE 1012 students make an informed decision regarding the suitability of Biosystems Engineering for their future careers. In the two years 66 students (91.7%) agreed or strongly agreed that the project helped them in making an academic career decision regarding Biosystems Engineering, which has been and will continue to be one of the primary objectives of the introductory course. Mann-Whitney rank sum tests suggested no statistically significant differences in comparing the responses between Fall 2012 and Fall 2013 (Table 3).

Survey Question	Fall 2012 Median (25%, 75%)	Fall 2013 Median (25%, 75%)	p value
Design project was worthwhile	3.0 (3.0, 4.0)*	3.0 (3.0, 4.0)	0.086
Design project increased my understanding of engineering	3.0 (3.0, 4.0)	3.0 (3.00, 4.0)	0.819
Design project and interaction with seniors helped in making an infored decision regarding the suitability of Biosystems Engineering	3.0 (3.0, 4.0)	3.0 (3.0, 4.0)	0.435

*Ratings correspond to the following scale: 1.0 – Strongly Disagree, 2.0 – Disagree, 3.0 – Agree, and 4.0 – Strongly Agree.

Table 3. Statistical tests related to the survey responses of BAE 1012 students in Fall 2012 versus Fall 2013 semesters.

BAE 4012 Survey Results

Survey results from the senior design students suggested unique responses between the two years (Fig. 2). In the Fall 2012 semester, only 75% of the seniors agreed or strongly agreed that the project was beneficial for the BAE 1012 students; only 31% agreed that working with BAE 1012 teams assisted their senior design project team. With this being the first year of implementation, these results are most likely influenced by the unfamiliarity of the senior design students with appropriate strategies for utilizing the talents and skills of the BAE 1012 students. More specifically, note in Table 1 how many of the BAE 1012 student projects were actually designs related more so to the entire senior design project rather than a specific subset or aspect of the project.

While not testable because of the anonymity of the surveys, it was hypothesized that a relationship existed between whether the senior design students isolated a subset of the projects for their BAE 1012 student teams and whether they rated the linkage as worthwhile. In general, the senior design students during the Fall 2012 semester had more difficulty developing strategies to separate their entire design projects into a reasonable project for the BAE 1012 student teams. Interestingly, the majority of students agreed or strongly agreed (69%) that the projects should be linked in the future. Several of these students had participated in the BAE 1012 research-based projects early in their academic careers and believed in the benefit of a design-based approach for BAE 1012.

Corresponding survey results of students after the Fall 2013 semester suggested a much different response to the project linkage by the senior design students, much of which could be due to familiarity with the requirement of working with a BAE 1012 student teams. Only one of the eight student projects (12.5%) required the BAE 1012 students to attempt to solve the entire student design project rather than a specific subset or aspect of the project. In fact, this was the case for this single project because of delays in receiving items from the client for initial testing, which the BAE 1012 student team was going to lead. These smaller projects helped the BAE 1012 students identify a specific task within the larger

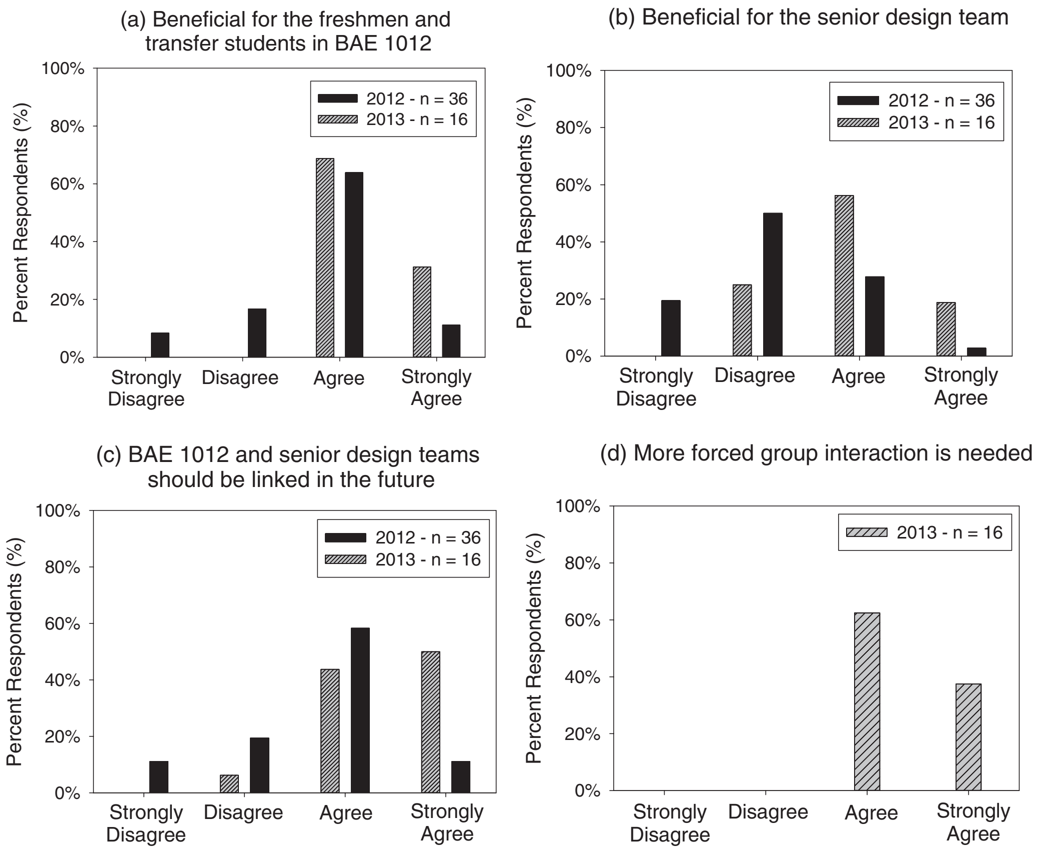

Figure 2. Results from the surveys of senior design students in 2012 and 2013 regarding the linked projects.

project to where they could make an appropriate contribution. In fact, almost all senior design teams acknowledged their BAE 1012 design partners in their fall senior design presentations, something that only occurred in one or two cases during the Fall 2012 semester. All the senior design students (100%) agreed or strongly agreed that the project was beneficial for BAE 1012 students; 75% agreed or strongly agreed that the linkage was beneficial for the senior design project team; and 94% agreed that the student teams should be linked in the future. As expected, Mann-Whitney rank sum tests suggested statistically significant differences between the Fall 2012 versus Fall 2013 senior design students responses (Table 4).

Current and Future Changes in Linkage

The two-semester senior design course structure at OSU is one of the most significant advantages for successfully carrying out the proposed linkage between first-year and senior engineering students. Senior engineering students were more inclined to mentor first-year students during the

Survey Question	Fall 2012 Median (25%, 75%)	Fall 2013 Median (25%, 75%)	p value
Linkage was beneficial for BAE 1012 students	3.0 (2.3, 3.0)*	3.0 (3.0, 4.0)	0.012
Design project increased my understanding of engineering	2.0 (2.0, 3.0)	3.0 (2.3, 3.0)	0.001
Design project and interaction with seniors helped in making an infored decision regarding the suitability of Biosystems Engineering	3.0 (2.0, 3.0)	3.5 (3.0, 4.0)	0.002

*Ratings correspond to the following scale: 1.0 – Strongly Disagree, 2.0 – Disagree, 3.0 – Agree, and 4.0 – Strongly Agree.

Table 4. Statistical-tests related to the survey responses of senior design students in Fall 2012 versus Fall 2013 semesters.

fall semester when they were focused on idea generation, patent and standard research, and selection of a final design from alternative solutions rather than prototype development, construction, and testing. Their willingness would diminish if they were also expected to complete their senior design projects during this mentoring period.

The most common theme from the seniors' comments was the need for more forced interaction between the groups, especially in terms of consistency in engaging all BAE 1012 project team members in participating. A change was initiated for the Fall 2013 semester to emphasize the importance of mentoring by the senior design students (Meyers et al., 2010). Unique to the fall 2013 semester, the senior design instructor included mentoring of BAE 1012 teams as a small percentage (5%) of the senior design course grade for the fall semester (i.e., BAE 4012). It has also been suggested that lecturing to the seniors on mentoring as a key leadership skill may be beneficial for the fist-year/senior student linkage and also for the overall development of the senior engineering students.

To further assess the degree of interaction, an additional question was added to the senior surveys at the end of the Fall 2013 semester. The seniors were asked whether they agreed or disagreed with the statement that more forced group interaction was needed between BAE 1012 and BAE 4012 teams, and the results were consistently supportive for more forced interaction (Fig. 2). In response to the survey data, the lecture meeting times for BAE 1012 will be adjusted starting in the Fall 2014 semester to align with the course time for BAE 4012 one day of the week. The two classes will meet together every two to three weeks after projects teams have been established in both classes to ensure interaction between the teams.

CONCLUSION AND SUMMARY

Two years of assessment data were gathered on linking first-year and senior design engineering teams, including an analysis of poster evaluation scores from quantitative rubrics and qualitative surveys of both BAE 1012 and BAE 4012 students. As a result of linking first-year and senior engineering teams, early academic career engineering students are able to effectively decide on whether engineering, and more specifically Biosystems Engineering, is an appropriate career path. Senior design students were initially passive regarding the linkage but as the linkage has become institutionalized these students have accepted their mentoring roles and view the ability to work with BAE 1012 student teams as positive for their senior design experience. An important aspect relative to this linkage was the need for senior design teams to identify an appropriate subset of their design projects for the first-year project teams. Future changes will continue to be made to more appropriately link these student teams to foster engagement and interaction among both the BAE 1012 and BAE 4012 students. It is hypothesized that similar strategies may be beneficial at other institutions, especially for small and medium sized programs, where first-year engineering students enroll in introductory engineering courses. A two-semester senior design course structure was important for creating a structure to carry out the proposed linkage.

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