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Student Perspectives in an All-Female First-Year Engineering Innovation Course*

KIMBERLY E. BIGELOW
Department of Mechanical and Aerospace Engineering, University of Dayton, 300 College Park, Dayton, OH 45469–0238, USA.
E-mail: Kimberly.Bigelow@udayton.edu

In Fall 2008 the University of Dayton first offered their restructured first-year design course entitled Engineering Innovation. A year later an all-female section of the course was offered, in conjunction with the development of a Women in Science and Engineering Living Learning Community. Now having finished the second year of this initiative, this paper focuses on student perspectives of having been in an all-female engineering design class. Reflection papers written by the students detailed both perceived benefits and consequences of the all-female class experience. This paper examines these perceptions and discusses the implications these perceptions have for teaching traditional mixed-gendered innovation courses so that they might be more inclusive to all students.

Keywords: engineering design; women in engineering; first-year experience; project-based learning; living learning communities

1. Introduction

For more than the last decade there has been a push to increase the number of engineers in the US to stay globally competitive [1]. More recently, this focus has shifted on not just producing technically skilled engineers, but engineers who possess creativity and ability to innovate [1, 2]. Despite this push, the number of practicing engineers in the US remains relatively low, with a growing concern that there may become a shortage of engineers and scientists in the near future [3, 4]. This has been attributed, in large part, to the disproportionately small numbers of females and minorities in the profession [4, 5]. Recent statistics from 2005 indicate that only 26% of the US engineering workforce was female, despite the fact that during this same time half of all management, professional, and related occupational positions in the U.S. were held by women [6]. Minority presence in the profession is even lower, with only 5% of the non-academic engineering workforce being black and approximately 5% being Hispanic [4].

Efforts have therefore shifted to engineering preparation programs. A particular focus has been on the recruitment and retention of undergraduate engineering students, especially females and minorities [2, 7–9]. Nationally, retention rates for engineering students have been estimated to be approximately 56%, with female and minority retention rates much lower, around 30% [10]. The majority of students who leave engineering do so in their first- or second-year [11], indicating that the first-year experience is a particularly pivotal time to encourage and keep students engaged in the major.

As such, the first-year experience within engineering has been a main focus for a number of efforts aimed at improving student retention [e.g. 10, 12, 13]. There has been suggestion that this focus has helped shift the nature of first-year engineering courses from courses that are intended to 'weed out' students, common in previous years, to a curriculum that better helps students have increased exposure to typical engineering work while also improving self-efficacy [12]. For the large part the implementation of such revised curriculum remains largely institution-specific, though some models of successful first-year programs have been suggested [e.g. 10, 14]. However, there have been a number of common elements that are recognized as important in developing such a course in an effort to improve likelihood of retention. Jones et al., for example, found that after the first-year of engineering education many students reported less enjoyment in engineering, and viewed it as less useful and less important than they had prior to beginning college [13]. These findings led the authors to suggest that course curriculum focused on retention should ensure that engineering is portrayed as enjoyable work that is significant [13]. Course elements that help achieve this have included design-related projects, team-based work, and close interaction with faculty [e.g. 10, 14]. Because many of these elements are fundamental in many institutions' senior capstone engineering design courses, these capstone courses have the potential to serve as a model for first-year 'cornerstone' design courses [15]. This paper begins by describing such a course, and then goes on to describe an innovative initiative to cohort female students into an all-female course section.

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2. Engineering innovation course

In recognizing the importance of the early college engineering experience, several years ago the University of Dayton restructured the experience by creating a common Integrated Engineering Core (IEC) curriculum. This initiative brought first- and second-year engineering students together, regardless of major, to take foundational engineering courses like statics, thermodynamics, and circuits. One of the ideas behind the IEC was that it would allow students to better see the relationship between fundamental concepts, all of which transcended specific discipline. This, if successful, has the potential to foster an interdisciplinary appreciation in students which could have long-lasting effects.

In developing the IEC curriculum, there was agreement that there needed to be a strong foundational first-year engineering design course. This led to restructuring a previously existing Introduction to Engineering-type class to increase the emphasis on innovation in the engineering design process through project-based learning.

The newly developed course, *EGR 103 Engineering Innovation*, first offered in Fall 2008, is a two-credit, one-semester course required for all first-year engineering students as part of the IEC curriculum. Approximately seven sections, each of approximately 24 multidisciplinary students, are offered each semester, with each section taught by one of a small team of instructors. The instruction team, with representation from all engineering departments, meets regularly to coordinate the structure of the class, as well as common elements and practices. The central theme of the course is the formulation of solutions to real-world engineering design problems by applying the engineering design and innovation process. This includes the steps of problem definition, creative ideation, concept development, design decision analysis, detailed design, model/prototype building, testing, and justification through written report and oral presentation.

Working in teams of approximately four, students spend the first month of the semester applying the engineering design and innovation process to a fairly contrived and well-defined problem, common for all EGR 103 sections. For the past few semesters this introductory small-scale project has been to create a cardboard chair/table that can support 400 lbs. with limited materials (1 sheet of $3' \times 6'$ cardboard and 10 glue sticks) and limited time (75 minutes for construction). A competition is held across the sections and students seem excited and surprised to see how well their designs do, seemingly building their own confidence in their engineering abilities. Once students have had the chance to practice the design and innovation process and receive feedback on their reports and presentations, the remainder of the semester is spent on a much larger, ill-defined, real-world problem.

This second project mimics the successful model laid forth by the University of Dayton's Design and Manufacturing Clinic senior capstone design courses. As with the senior capstone courses, these projects are driven by real needs of local business or community partners. These partners then become mentors for the class, helping students define the problem and then providing constructive feedback during conceptual design reviews. The actual topic of the project is left largely up to the individual instructor for any given section, and often aligns with their own area of expertise and any current industry or community partnerships that exist. In contrast to the senior capstone model, however, it is often the responsibility of the instructor to come up with a probable topic or problem and then approach the partner to serve as a mentor, rather than the other way around.

The emphasis of the second project is often service-learning-based, with projects focused on problems related to disability, sustainability, or appropriate technology for developing nations. As such, there tends to be more community or educational partners than industrial partners. Most projects are particularly ill-defined, requiring students to do significant background research to better define the problem, with the freedom to pursue any number of design directions. It is thought that this flexibility in project scope helps students begin to develop opportunity recognition skills, furthering the goal to promote innovation and entrepreneurship in the curriculum. Past problems to be solved included the need for individuals who are homeless to stay warm during the winter despite frequently moving locations, the desire of farmers with disability to safely maintain their profession, and the growing opportunity to teach younger children engineering and sustainability through inspiring and educational hands-on activities.

Since its initial offering, this course has been very positively regarded. End of Semester Survey data from students who took the course in Fall 2010 indicate that student feelings were very strong with regard to the expected outcomes of the course. Table 1 shows, based on a likert scale of 1 to 5, the percentages of students responding 'strongly agree' (5) or 'agree' (4) to key survey questions.

3. Development and rationale for an all-female section

Similar to the motivation for improving the first-year experience for engineering students, the disproportionate number of female students in the

Table 1. Student Survey Response to Important Course Objective-Related Questions for Fall 2010

Survey Statement	% of Students Responding 'Agree' or 'Strongly Agree'
As a result of working on this project I have enhanced my ability to design components and/or processes to meet needs.	94%
This course improved my understanding of the role of engineering to serve society needs.	94%
Through these projects and the design process I believe I am able to develop creative and innovative solutions to engineering problems.	93%
Because of the team projects I believe that I will be better able to function on multidisciplinary project teams.	93%
I believe I learned a great deal about design and the design process.	91%

engineering disciplines has led more universities, University of Dayton included, to pursue efforts to attract and retain females. One such recent effort at the University of Dayton is the offering of a Women in Science and Engineering Living Learning Community (WISE LLC), where first-year science and engineering students live together and take shared courses. Such Living Learning Communities allow students to develop social networks that can help provide support in academic pursuits and prevent a feeling of isolation.

The WISE LLC was structured so that of 40 students comprising the community, approximately 20 were first-year students with majors declared in engineering and 20 with majors declared in the sciences (a large majority of which happened to be pre-med). As all engineering students are required to take EGR 103 during their first-year, this became one of the common academic courses for the engineering students in the WISE LLC. In Fall 2009 the first WISE LLC cohort took *EGR 103 Engineering Innovation*. Of the 24 students in the course, 17 were engineering students from the WISE LLC and the remaining were other female first-year students selected to fill the section. Because Living Learning Communities have to be annually reviewed at the University of Dayton and this process occurs early in the academic year, the WISE LLC was renewed under the grounds that there was insufficient evidence to evaluate it and it would need additional time to determine its merits. Certainly, there was some concern that the segregation of females into an all-female engineering course might have some undesirable effects. Therefore, a second WISE LLC cohort entered *EGR 103 Engineering Innovation* in Fall 2010. This course was made up of 15 students from the LLC and 9 additional female students. Efforts to further evaluate the effectiveness of the WISE LLC set-up are currently ongoing.

Outside of the all-female make-up of the class and any instructor-specific differences in carrying out the course, there were no differences in course structure or content compared to the mixed gendered sections. Both the Fall 2009 and Fall 2010 cohorts were taught by the same instructor (a tenure-track female faculty member in mechanical engineering). This instructor only taught one section per semester, limiting direct comparison between the all-female course and an identical traditional mixed-gendered course during the same semester. However, the instructor taught the traditional mixed-gendered course in Spring 2009, Spring 2010, and Spring 2011, noticing many differences in the class and interactions among classmates.

4. Student reactions from the all-female class

To solicit student reaction to the EGR 103 engineering and design experience in general, as well as to the all-female nature of the class, an end-of-course reflection paper was assigned. Reflection papers are used sporadically throughout the *EGR 103 Engineering Innovation* curriculum to help students reflect on and process milestone activities, such as at the conclusion of the small-scale project and after the counseling center facilitates a Myers-Briggs activity on teamwork development. In the case of the final course reflection, students were assigned to write a minimum two-page double-spaced paper. They were provided a series of prompts that they could use to guide their reflective response, though they were not required to. The following prompts were provided:

- What did you learn from this experience?
- What changed between Project #1 and Project #2?
- What surprised you?
- Did you enjoy the experience? Were there parts you liked more than others?
- How did you function in a group?
- What do you want to remember from this class to help you in future classes?
- What did you think of your experience being in an all-female class?

For the Fall 2010 cohort, these reflections were evaluated to identify and categorize common themes. The instructor read through all papers and counted the number of students who provided a response that fit into one of the identified themes pertaining to the all-female class. Of 22 reflections, all but 2 students commented in some way about the

all-female nature of the course. Overall, the majority of students reported the all-female nature of the class to be enjoyable and/or beneficial, including 4 of the 8 reflections of students who had not self-selected to be in the section (non-WISE LLC members). Ten students directly commented that they liked and/or enjoyed the course and/or found it overall beneficial, with another implying the same. Another 5 students felt that the course was generally good, but also expressed that there were both pros and cons to such a course. Four other students, all of which were not members of the WISE LLC but had placed in the course, stated that they would have preferred a mixed-gendered class.

Table 2 shows the top three perceived benefits of the all-female engineering design and innovation course, and the top three perceived consequences, as judged by number of reflections stating each.

A central theme, present in over half of all of the reflections, related gender to the building of prototypes. Some students expressed fear and embarrassment in using the power tools in class due to lack of experience. However, many also expressed feeling that they had increased opportunity to practice using these tools and to become more comfortable with them than they would have in a traditional mixed-gendered course, where they assumed the prototype building would fall to more experienced male students. With this increased opportunity came new knowledge gained and seemingly pride by 'having to' use the tools. The opportunity to be involved in the actual building of the prototype was a perceived benefit that some students felt they would not have had if they were working in a group of male peers. Instead, these students felt that if males were present, their own contribution to the project would have been primarily related to the report writing and other organizational tasks. In contrast, 3 students commented instead that they felt that not having male students to substantially contribute to prototype and model building was a detriment. These students conveyed that females don't have enough building skill to prepare compelling prototypes, implying that the male presence would have enhanced their ability to create a more technical product. Interestingly, sewing played an important role in half of the class projects in the all-female class, with one student even proposing that if the school had a band saw then it should have a sewing machine too.

In addition to becoming more comfortable in the use of tools and having a perceived opportunity to be more involved in technical aspects of the engineering design and innovation process, another commonly identified benefit of the all-female class was the ability to work with similar people. Students implied that they felt their female classmates had a more similar work style and ethic to their own. This included a perception that the majority of females in the class were strong in organization, truly had passion in the course work and/or engineering career paths, and also were more likely to participate fully in the group work (as compared to males).

In contrast, the most commonly cited consequence of an all-female class was the absence of diversity of thought from the engineering design and innovation process. Students felt that the male presence would have brought new insight, perspectives, and general diversity to the designs. This may have been in direct response to a seminar that all of the EGR 103 course sections participated in related to innovation and the need for diverse teams to generate the best ideas. The speaker gave the example of a design idea that had failed because it was a baby product and yet there were no mothers or even females on the design team. This helped heighten the need for male presence in the class to generate better design alternatives. In light of this, students were given an opportunity to bring outside individuals that could cover any missing perspectives into class for brainstorming day, however no group did. It was clear, though, that students recognized that diversity of thought is important to be a successful and innovative engineering team and that without the male perspective they may be at a disadvantage.

The last perceived consequence was that some students felt that the presence of males in the classroom would have added a needed balance to the

Table 2. Top Three Perceived Benefits of the All-Female Engineering Design and Innovation Course and Top Three Perceived Consequences

Benefits	Students Reporting	Consequences	Students Reporting
1. Felt more comfortable expressing ideas and presenting; Felt less intimidated.	8	**1.** A male perspective could have brought new insight, perceptions, or diversity to designs.	6
2. Increased opportunity to use the tools and participate in all aspects of the design process, not just report writing.	4	**2.** Females did not have enough building skills to produce strong prototypes.	3
3. Worked with people of a more similar work style, organization, passion, and likelihood to participate.	3	**3.** Males would have added a needed balance to the course, limiting 'drama' .	3

class, particularly in eliminating 'drama'. Only three individuals mentioned this, and it may be that they were on teams that had occasional problems or personality clashes. One of the unique challenges as related to cohorting WISE LLC students, or any group of students who are in long-term contact, is that often issues peripheral to class carryover to class conduct and interactions. On occasion this has proven true in the *EGR 103 Engineering Innovation* course when conflicts occurring in the dorm surfaced in the classroom.

5. Implications for practice

University of Dayton's *EGR 103 Engineering Innovation* course, and the option of an all-female section, provides one possible model for teaching the innovation process at the first-year level. Overall findings indicate that offering an all-female course is feasible and is perceived by most students to be a beneficial experience. The longitudinal impact of this type of course offering is currently unclear. It does appear, however, that the placement of students who did not self-select to be in an all-female course has more mixed results—4 of 8 non-WISE LLC students responded positively toward the all-female nature of the course, with the other 4 having wished they had been in a traditional mixed-gendered class.

More importantly, the perceived benefits and consequences of students being in the all-female class provide insight into the ways courses might be structured to encourage all students, especially those historically underrepresented in engineering, to succeed. Engineering innovation courses, where students are often expected to build prototypes and contribute successfully to teams, may be especially susceptible to gender-differences.

The most significant perceived benefit of the all-female course was that students believed that they were more comfortable and less intimidated than they would have been in a mixed-gendered class. As the students taking this course had no prior experience being in an engineering course with males, it is unclear whether these concerns would have played out or been left unfounded. Regardless, it was clear that at least 40% of the class had the perception that male students would have not listened to their opinions and/or that they would not have felt as comfortable sharing ideas with male peers. The all-female nature of the class enabled the increased level of participation from individuals who may have stayed quiet in a traditional course. The main implication of this is that there may be a need for educators in design classes to be cognizant of such students and provide avenues so that all team members can contribute without feeling fear or embarrassment. One way in which this can be accomplished is through utilizing design and innovation methods that allow for a time of individual reflection, brainstorming, and/or sketching prior to moving on to group activity. One such particularly effective method for ideation is the use of post-it note brainstorming [16]. In this method, all individuals involved spend a set time individually writing design alternatives on post-it notes. Individuals are encouraged to be outlandish, incomplete, and go for quantity. After the set time for independent work has elapsed, students then go around the team, and one-at-a-time read and presents one of their post-it note ideas to the group. The group does not discuss, but rather jots down ideas that this makes them think of on new post-it notes. Such a method not only improves innovation of ideas, but also ensures full participation by all and does so in a fairly comfortable setting and manner. It is hoped that by building confidence early, later in the engineering curriculum feelings of intimidation or fear around male peers will be much reduced, though research is needed to ensure that this does happen.

Another important theme that emerged was related to tool use and prior hands-on knowledge. A number of females in the class had limited experience using tools, and were therefore initially uncomfortable and fearful of using the power tools for building. Because of the large proportion of the class in this situation, this was proactively addressed in three main ways. The first was that at the beginning of the course the team-making survey tool CATME Team-Maker [17,18] was used to create teams in a way that distributed individuals with prior woodshop/machine-shop experience evenly. CATME Team-Maker is an on-line, freely available software that allows the instructor to pre-select questions of interest that can be used to pair teams. Students then respond via web-based survey, and CATME Team-Maker assembles the teams based on the instructor's desire to group similar or dissimilar students for various criteria, such as prior shop skill. A second initiative was the offering of an optional introduction to woodworking workshop specifically for the WISE LLC. This was done prior to the prototype building portion of the course. A facilitator helped students build a functional shelving unit that could be used in their dorm room, while teaching students through the activity fundamental skills in basic tool use. This event was followed-up with a module that all *EGR 103 Engineering Innovation* students participated in, which was a tool safety training organized by the School's safety officer. Students were first taught and then had to demonstrate an ability to work with various hand tools, power tools, a drill press, and a band saw. Instruction included basics such as how to

remove a battery from a battery-powered drill and how to change a saw blade in a jigsaw, all of which students were then required to demonstrate an ability to do. Though seemingly basic, this was very important that everyone got the same information and helped individuals with lesser experience without singling them out. Such activities when implemented in a mixed-gendered class may serve to accelerate the learning curve and comfort of students with less experience using tools, both male and female. Indeed, in this case, students began prototype building with increased enthusiasm and did so safely. This is further demonstrated in the reflections which noted pride at using tools.

Related to this is a student perception that if males who were sufficiently experienced with tool use were in the class, female students with less experience may never have gotten a chance to try. Especially at the first-year level, it may require facilitation as the instructor to ensure that roles are divided fairly, perhaps even forcing rotation of group members between various roles. Often more experienced students are happy to help demonstrate and encourage a team member, but may not automatically think to do so unless prodded by the instructor. A related concern as conveyed by the reflections was that female students felt that they would most likely be assigned more organizational-type or a secretarial role in a mixed-gendered group, and indeed this commonly happens. One easy way to overcome this in the set-up used by *EGR 103 Engineering Innovation*, which has two distinct course projects, is to re-assign team roles when Project 1 is complete such that everyone gets practice taking on different roles in the engineering design and innovation process. Such roles might include project manager, lead designer, technical editor, production supervisor, and team recorder.

Another concern regarding prototype building was that some of the all-female class students felt at a disadvantage because the teams, as a whole, had significantly less prior experience using tools or even familiarity with building materials and hardware than traditional teams, limiting them in what they could create. These students felt that they could have built a much more technically sophisticated functional device if they had males on their team, with the assumption that the majority of males had prior experience. Perhaps it is in light of this that so many of the designs took a more creative or arts-and-crafts style spin. This is not to say that the resulting prototypes were not sound ideas and carried out well, but rather materials such as foam board and hot glue were used, and elaborate sewing projects were carried out. Material requisition has been substantially different for the all-female classes taught, with more trips to crafting and fabric stores for supplies such as modeling clay, metallic paint, fabric, and colored markers. Many teams still do need some 'traditional' supplies such as lumber and screws, but these are often in addition to the crafting material. Though not entirely conventional within the scope of engineering design courses, these craft-type supplies seemed to enhance the creativity of the projects made, often resulting in more aesthetically pleasing prototypes. In practice, this may mean that instructors want to be proactive in providing such materials and/or making it known that materials can be purchased from such stores. It is likely that all students would benefit from the creative and artistic expression, one which females may be more apt to think of, but may also be uncomfortable to suggest per the earlier discussion on intimidation when proposing ideas—i.e. not wanting to look foolish. As one of the students suggested in her reflection, design clinics may also want to consider purchasing less conventional tools and equipment, such as a sewing machine. For the number of teams that undertook some form of sewing in their projects, the time that had to be devoted to sewing by hand took up a good portion of the allotted prototype building time. A sewing machine would have increased productivity and ease of building, just as a band saw is more commonly used than sawing by hand.

Though not exhaustive, it is thought that these practices may help engineering design and innovation courses better accommodate diverse individuals, particularly females and other traditionally underrepresented groups. Such efforts, many quite easy to implement, may provide the supportive environment that ultimately increases student retention, leading to a stronger and more diverse workforce.

6. Conclusions

In conclusion, the lessons learned from an all-female first-year engineering design course lead to the following recommendations, which may make all engineering design classes more inclusive:

- Use surveys such as CATME Team-Maker [18] to ensure students with prior shop and woodworking experience are fairly distributed among teams
- Encourage brainstorming methods that allow students who may be introverted a structured time to share ideas with the group after a period of independent thought (e.g. Post-It Note Brainstorming)
- Provide tool safety training and optional out-of-class workshops where students can learn to use tools while building something useful in a more social environment

- Visit arts and crafts stores for prototype-building supplies, to compliment more traditional materials purchased at lumber and hardware stores. Doing so will often have the added benefit of an increased attention to aesthetics of the prototypes
- Consider the purchase of a sewing machine to add to a traditional machine shop
- Carefully monitor student roles within the team, encourage rotation so that all students actively participate in all steps of the process

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Kimberly Edginton Bigelow has been an assistant professor in the Department of Mechanical and Aerospace Engineering at the University of Dayton since January 2009. She also serves as one of the faculty for the Women in Science and Engineering Living Learning Community. She directs the Engineering Wellness and Safety Laboratory, with expertise in whole body biomechanics and the interface between engineering and human health. In addition to teaching the *EGR 103 Engineering Innovation* first-year design course, she teaches Engineering Experimentation and Biomechanical Engineering. Her educational research interests include retention of women and minorities, use of reflection to enhance student learning, and technical communication. Dr. Bigelow completed a B.S. in Engineering Mechanics at Michigan State University (2003), an M.S. in Mechanical Engineering at Ohio State University (2005), and a Ph.D. in Mechanical Engineering, also at Ohio State University (2008). She has presented several papers at the American Society of Engineering Education Meeting, and recently published work relating to the use of web-based forums to connect to practicing engineers in the *Journal of Applications and Practices in Engineering Education.* In 2010 Dr. Bigelow was awarded the American Society of Engineering Education's Women in Engineering Division's Apprentice Educator Grant Award.