Paper Title: Computer-based design tools in engineering – steps to ensure a gender-inclusive learning environment

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Synopsis (400 words only):
At the University of Guelph (Guelph, ON Canada), second-year engineering students are introduced to I-deas® (UGS,TX USA), a sophisticated tool for computer-aided engineering (CAE), and they use some of its capabilities for 3-dimensional drawing and finite-element analysis. Course enhancements have been developed to improve self-directed learning resources for the software and to encourage students to participate in collaborative learning. One of the major assignments in the second year design course is the creation of a 3-dimensional drawing of an engineered component. Each student group disassembles a large component (e.g. home appliance, process equipment, automobile components) and each member of the group takes one part as their individual drawing assignment. Strategies have been integrated into the task to encourage and reward collaborative approaches. Opportunities to earn bonus marks are linked to helping peers learn software skills that are necessary to draw their individual parts. There are also bonus rewards for groups who collaborate to electronically reassemble their individual parts into the original component.

A program logic model was developed that linked specific changes in course delivery to in-course and immediate post-course goals. Students completed surveys at the beginning and end of the design course in 2003 and 2004 and they were observed in different learning environments (computer laboratories and machine shop) in 2003. Quantitative and qualitative assessments were completed to monitor self-efficacy ratings in a number of course-related domains (e.g. computer software, engineering skills), attitudes towards help-seeking, help-giving and help threat, and assessment of overall collaborative environment (final survey only). Responses for the 2003 and 2004 surveys were combined and analysed by gender.

- Females had lower computer-use self-efficacy than males but were not “low” in absolute terms.
- Females reported significantly lower confidence in using CAE software than males at the pre-course survey but this finding was not present at post-course evaluation.
- Females reported lower self-efficacy in engaging in hands-on work and felt they had less opportunity to do so.

Confidence in using CAE software was correlated with self-efficacy in engineering design and hands-on mechanical skills at pre- and post-course surveys. The correlations at post-course were higher at pre-course but the differences were not statistically significant. All students were more likely to ask a student they did not know for help at post-course and overall ratings of “help atmosphere” were high.

Computer-based design tools in engineering – steps to ensure a gender-inclusive learning environment*

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Synopsis:
Engineering programs related to computing (e.g. computer engineering, engineering systems and computing) have expanded recently as a result of the Ontario Ministry's "Access to Opportunities Program". Preliminary statistics indicate that the participation rates for women in these programs are low. For example the percentage of women in the first-year class in Engineering Systems and Computing at the University of Guelph has been below 10% over the past five years compared to participation rates higher than 35% in Biological, Environmental and Water Resources Engineering. There are many factors that contribute this statistic but one common response from female students is an aversion to programming courses.

Furthermore the use of computer-based tools is increasingly in undergraduate programs in engineering and the physical sciences. Formal instruction is given for some tools but students are expected to learn a fair amount independently. Are female students comfortable with this? Does the technology have a negative effect on their motivation to continue in engineering programs? Are there better pedagogical approaches that do not have a gender bias?

At the University of Guelph, second-year engineering students are introduced to IDEAS® (SDRC), a sophisticated tool for computer-aided engineering (CAE), and use some of its capabilities for 3-dimensional drawing and finite-element analysis. Course enhancements have been developed to improve self-directed learning resources for the software and to encourage students to participate in collaborative learning. The CAE task of creating a 3D drawing of an engineered part is a challenging and potentially isolating task. Thus, strategies have been integrated into the task to encourage and reward collaborative approaches. Opportunities to earn bonus marks are linked to helping peers with their individual parts. Two bonuses are awarded, one based on ratings of helpfulness from students in the same section and the second based on ratings from all students in the class. The third bonus rewards sections of students which attempt to electronically reassemble their individual parts into the original component (e.g. appliances, industrial equipment). Success in this respect required collaboration from the outset and helps students recognize that engineering systems are comprised of many parts and it is essential that the parts all fit together.

Students completed surveys at the beginning and end of the course in 2003 and 2004 and they were observed in different learning environments (computer laboratories and machine shop) in 2003. Quantitative and qualitative assessments were completed to monitor self-efficacy ratings in a number of course-related domains (e.g. computer software, engineering skills), attitudes towards help-seeking and help-giving, and assessment of overall collaborative environment (final survey only). Responses were analysed by gender.

- Females were equivalent to males in multiple self-efficacy domains, including use of the CAE, abstract and design skills, oral presentations, and working in a team environment.

- Females had lower computer use self-efficacy than males but were not "low" in absolute terms; furthermore, females were not significantly lower in terms of

confidence using the CAE software, which represents the main computer component of the course.

- Females reported lower self-efficacy in engaging in hands-on work and felt they had less opportunity to do so. While this is concerning, this difference did not appear to relate to other efficacy areas or academic performance.

- The “helping attitudes” of females were more positive after course. In general helping attitudes were related to greater confidence using the CAE software. All students were more likely to ask a student they did not know for help at post-course and overall ratings of a “helping atmosphere’ were high.

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Full paper

Background

The University of Guelph offers four, fully accredited, non-traditional engineering programs. Over the past five years, the percentage of women in the Engineering Systems and Computing program has been below 10% compared to participation rates between 20 and 60% in Water Resources, Environmental and Biological Engineering. National data showed similar gender differences for engineering disciplines that focus on computer technology compared those with a life sciences emphasis (CCPE, 2005). The differences in participation rates may be understood as a function of larger societal values of masculinity and femininity. Dryburgh (1999) sees the profession of engineering as having a culture based on masculine values, rituals and images. Foremost among these is the requirement that competence as an engineer is a function of how well one presents an image of an aggressive, competitive, technically oriented person (McIlwee and Robinson, 1992). Further, previous studies have shown that male students enter engineering programs because of their interest in 'tinkering' (*ibid*) and that this pleasure in technology becomes a bond that excludes female students (Faulkner 2001). Ironically, female students often tend to perform better academically than their male peers, simply because it is academic competence that encouraged them to enter the engineering program (Dryburgh, 1999). It may be the case that the Engineering Systems and Computing program attracts students who are drawn to competitive demonstrations of technological competence, while the other programs may represent contexts for the performance of more feminine values of caring for others and working for the common good. Margolis and Fisher (2001), Ayre and Mills (2003), Pawley (2004) have also stressed the importance of explicitly including human and social contexts into computer science and engineering curricula to maintain the interest of female students in these subjects.

Although female students are not choosing to enroll in engineering programs with an obvious emphasis on computers and information technologies (IT), these have become key components of education and practice for all engineering disciplines. In her keynote address at the 11th GASAT conference, Parker (2003), outlined five basic expectations for gender-inclusive information and communication technology (ICT), including pedagogy emphasizing interpersonal negotiation, human interaction, language, active participation by students and real-life contexts and tasks drawing on contexts which are familiar to both males and females.

Our research on various aspects of student performance in a second-year engineering course which develops computer-aided engineering skills is based on the assumption that larger societal values of masculinity and femininity manifest themselves in student behaviour to different degrees in different contexts, and that particular aptitudes and inclinations which interfere with successful learning may be countered by pedagogical strategies. However, it is clear that some settings and activities are less pedagogically manageable than others.

Engineering and Design II

Engineering and Design II is a required course in all four programs (Biological, Engineering Systems and Computing, Environmental and Water Resources) in the School of Engineering, University of Guelph. The course focuses on principles of engineering design and their practical application. The course has some additional goals: introduction to the use of computer aided engineering (CAE) software, strengthening team skills, provide a focus on oral communication skills, and provide an opportunity for hands-on experience. In 2003, funding was secured to make pedagogic enhancements for the CAE component of the course and to evaluate the success of these changes.

One of the motivations from the start of the project was to ensure a positive learning environment for female students. In this design course, formal instruction is given for basic

CAE skills but there is an expectation of a fair amount of independent learning. Are there gender differences in use of teaching resources (i.e. help-seeking from instructor or teaching assistants, from peers or using self-directed learning resources)? Do the technical tools for CAE have a negative effect on female student's self-efficacy related to engineering design and potentially their motivation to continue in engineering programs? Do female students prefer pedagogical approaches that emphasize interactional and collaborative learning?

<u>CAE component of Engineering and Design II</u> – One of the major assignments is the creation of a 3-dimensional drawing of an engineered component. Each student group disassembles a large component (e.g. home appliance, process equipment, automobile components) and each member of the group is assigned one or more parts as their individual drawing assignment.

I-deas® software (UGS,TX USA), a sophisticated tool for computer-aided engineering, was first introduced into the design course for 3-dimensional drawing in 2001. Students learned the basic components of the software in introductory tutorials that were guided by teaching assistants. However, given the diversity of the individual parts in the drawing assignment, students collectively used more features and dimensions of the software than could be presented in the introductory tutorials. Also not all of the teaching assistants had prior experience with the I-deas® software. In recognition of this, the pedagogic enhancements introduced in 2003 included a set of electronic learning aids (tutorial set, glossary, checklists) to help students and teaching assistants identify and learn course-specific skills and to provide convenient reference materials for the CAE software. A training workshop, open to all graduate students, was presented in July 2003 followed by more focused training sessions once teaching assistants were selected for the course (last week of August). These sessions used and tested the electronic learning aids. All electronic learning aids were available to the students via WebCT (a web-based course management tool) when the course began in September 2003.

In addition to the self-directed learning tools, the instructor took several steps to encourage collaborative learning among peers. Since each student had a unique part, the academic integrity risk associated with encouraging collaboration between students was virtually eliminated. At the beginning of the semester, the instructor provided formal encouragement to collaborate in learning software skills and introduced an assessment system with team and class bonuses. The rules for these bonuses were explained in the course outline as follows:

"Team & Class Player Bonus: The software is complex. Neither your instructor, your TA's or your colleagues will have all of the answers/techniques. Helping each other will speed the learning process for all (helping does not include doing someone else's work - that is academic misconduct!). A 15% bonus will be provided to the top 20% of the students in your section based on your collective feedback. A 10% bonus will be provided to the top 5 students in the class based on your collective feedback. (During Week 8, you will be asked to distribute 15 points among the members of your section, not just your product. A maximum of 5 points to any one individual. The individuals getting the most points within your section will receive the 15% bonus. You will have an additional 5 points to allocate to up to 5 individuals that aren't in your section. The top 5 students in the class as a whole will receive a 10% bonus.)"

Each team was encouraged to use the software to reassemble their complete component from the individual parts. This reassembly had numerous advantages. Students had to work together in the reassembly; they saw that their part had to fit into an overall system and the reassembly provide immediate feedback about the quality of the virtual renditions of individual parts. To encourage this reassembly attempt and the thinking that goes with it, an assembly bonus (up to 25%) was introduced to reward teams that were able to include at least one-third of the members' parts into a virtual model of the original component.

Evaluation Methods - A program logic model was developed that linked specific changes in course delivery to in-course goals (increased help-seeking and help-giving behaviour, increased computer skills) and immediate post-course goals related to enhanced feelings of self-efficacy in design engineering. The logic model was used to develop pre- and post course surveys which were used in 2003 and 2004. Students completed surveys at the end of a regular lecture in the absence of the instructor. Confidentiality was ensured and students were given the choice of participating or withdrawing from any aspect of the evaluation. When reporting responses, all participants were anonymous to faculty in the School of Engineering. Quantitative and qualitative assessments were completed to monitor self-efficacy ratings in a number of course-related domains (e.g. computer software, engineering skills), attitudes towards help-seeking and help-giving, and assessment of overall collaborative environment (final survey only). Survey results included gender identification and male and female responses were analysed as separate groups. The qualitative assessment included 10 hours of direct observations of laboratory (computer and machine shop) sessions and semi-structured interviews with 12 volunteer students in the class in 2003 (Hayward, 2004).

Discussion

Demographic information – In Canada, about 25% of the population between the ages of 18 and 22 attends university (Statistics Canada 2003). The University of Guelph is a publicly funded institution and one of 15 universities that offer engineering programs in Ontario. Participation rates for females in Guelph's undergraduate programs are high: 62% overall for the university and 28% across all engineering programs. The undergraduate population in engineering mirrors the ethnic diversity of urban centres in Ontario. About 19% of the students are visible minorities with close to an equal number of female and male students in this group.

The 2003 survey data were analysed at the beginning of 2004 as a unique data set. When the surveys were repeated, the 2004 data was also analysed as a separate set. Since the results were similar to the 2003 results, all of the student responses were collapsed into a single data set to increase the statistical power of the analyses. The 2004 cohort of students was substantially larger than the 2003 cohort but the groups were similar in terms of the profiles by gender and program as shown in Tables 1 and 2. The 2004 group had an overall higher grade for the CAE assignment but the grades were high for both cohorts (94% for CAE assignment in 2003 and 96% in 2004) as a result of the bonuses available.

Table 1 – Gender Distribution for Fall 2003 and Fall 2004 Cohorts

	Fall 2003	Fall 2004
Male	108 (72%)	196 (74%)
Female	41 (28%)	68 (26%)

Table 2 – Program streams for 2003 and 2004 Cohorts

	2003 (total #, % within program)	2004 (total #, % within program)
Engineering Systems & Computing	66, 6% F	118, 4% F
Environmental	40, 38% F	63, 33% F
Biological	34, 59% F	68, 56% F
Water Resources	9, 22% F	15, 20% F

Results - It was hypothesized that improvements in help-seeking attitudes would lead to a number of positive outcomes for students. Help-seeking behaviour and the helping atmosphere were assessed both quantitatively and qualitatively. Using a 5-point agreement scale, students' opinions were examined as to how likely they would be to seek help with their course work from formal sources (teaching assistants and the professor). Ratings for these most formal sources of help were low and there was a significant decrease at post-test ($mean_{pre} = 1.94$ vs. $mean_{post} = 1.72$). There were no gender differences on these measures. This low rating was disappointing but it likely reflected restricted accessibility outside of scheduled laboratory times and some shortcomings in training the teaching assistants and the professor.

Students' willingness to seek help from a student that they did not know was examined. On a 5-point agreement scale, there was a significant increase between the pre- and post-course assessments ($mean_{pre} = 2.56$ vs. $mean_{post} = 2.93$). Student interviews confirmed this data. A couple of student comments were: "We help each other. I would ask anyone who was around. I feel like everyone is willing to help." and "We're all in the same boat. It's too much to learn alone. I couldn't do it without my friends. It's a team effort on everything."

A positive "help atmosphere" is necessary to encourage interactional learning. Since it is "what actually occurs" in the course, it can not be evaluated at the beginning of the course (i.e. there is no baseline). The post-course survey included a 5-point agreement scale that asked students questions to assess overall perception of the "help atmosphere" and Table 3 provides the item means by gender but none of the differences were statistically significant.

Table 3: Overall help atmosphere (combined 2003 and 2004 data)

Help atmosphere item (5-point scale)	Post-course mean	
	Males	Females
There were other students in this course that I could rely on to help me if I was having difficulty with the course material	3.88	4.02
In general, other students in this course were willing to help me if I needed it.	4.30	4.40
In the computer lab, I felt comfortable asking other students for help with the I-deas software	4.07	4.33
OVERALL	4.08	4.25

The last question under "help atmosphere" was particularly important since the competent use of the CAE software was an important part of the course. Clearly females felt comfortable seeking help around this course component although none of the means were significantly different from the means for male students.

In pre- and post-course assessments of computer self-efficacy, males reported significantly higher ratings than females but ratings for both genders were high in absolute terms (means > 4 on 5 point scale). Students were also asked to rate their confidence in using the CAE software, using a 5-point agreement scale. All the individual items (with the exception of "sketching in 2D"), and the mean score overall were significantly higher at post-course than at pre-course as summarized in Table 4. This provides even stronger evidence that students' understanding and skill in working with CAE program increased.

Table 4 – Confidence in using CAE software

How confident do you feel… (5 point scale)	Pre-course	Post-course
…using the IDEAS interface (windows, menus, buttons, icons)	**3.21***	**3.76**
…modeling parts (creating a new part, modeling methods)	**3.16**	**3.89**
…sketching in 2D (creating shapes, establishing reference points, specifying geometric planes, modifying dimensions, shape editing, etc.)	3.60	3.67
…creating 3D parts (moving from 2D to 3D, extruding, revolving, modifying with fillets and shells, etc.)	**3.16**	**4.00**
…selecting specific entities (editing/modifying specific feature of part models)	**3.05**	**3.69**
…viewing parts (using different viewing options, changing appearance of part)	**3.40**	**4.00**
…generating geometric information (measuring distances, angles, surface area)	**3.08**	**3.71**
…managing parts projects (naming and organizing parts, using parts library, sharing among users)	**2.84**	**3.46**
…troubleshooting (correcting mistakes, recovering information & past operations, searching for errors)	**2.21**	**2.99**
…producing 2D printouts	**2.38**	**3.12**
Overall	**2.99**	**3.65**

(*bold values indicate statistically significant differences between pre- and post-course means)

Females reported significantly lower confidence in using CAE than males at pre-course, but this finding was not present at post-course (Table 5). This is quite encouraging, and suggests that gender gaps in this self-efficacy domain had diminished significantly by the end of the course. The change from pre- to post-course for females was not significant, but just barely, and would probably have reached significance if more females were present in the sample.

Table 5 – Overall Confidence in using CAE software by gender

	Pre-course	Post-course
Females	**2.86***	3.53
Males	**3.19**	3.67

(*bold values indicate statistically significant differences between pre-course means)

Analysis indicated that confidence in CAE skills was negatively correlated with help threat at both pre-course (r = -0.12) and post-course (r = - 0.24). This implied that as students' perceived threat in asking for help decreased, their confidence in their CAE skills increased. The post-course correlation was higher than pre-course which provided some evidence that increases in interactional, relational learning were related to increased student confidence with CAE although the difference between pre- and post-course was not statistically significant.

The award of the bonuses for the CAE task confirmed that the females were at least as equally skilled as their male counterparts and that their peers recognized this skill. In 2003, females (29% of class) were awarded 39% of the 36 team and class bonuses and in 2004 females (26% of class) were awarded 21% of the 67 bonuses.

Females reported significantly lower confidence in their hands-on skills at both pre- and post-course surveys. Significantly fewer of the female group felt they had as much opportunity as other students to participate in activities and leadership roles in the machine shop. In 2003, an external observer noted interactions in the workshop as students took apart an old automobile.

> *Student lab groups tended to divide up into three clusters when faced with the task of the disassembly of an engineered part in the machine lab. These included uninvolved bystanders, hands on work participants, and administrators who did the note taking and the organizing of the parts. Male and female group members were both in the administrator cluster and in the bystander cluster. However, hands-on workers were usually male. In one case, one male dominated the whole process and drew in a few male assistants who handed him tools and consulted with him about strategy.*
>
> *Lab assistants admonished all members of the group to become involved in the process of the actual disassembly of the part, often using the phrase that everyone should have a chance to get their hands dirty. Some male students seemed to enjoy the process of getting grease on their hands, rubbing the grease into their skin. Female students, on the other hand, carefully held their soiled hands away from their clothing and were quick to clean off any bit of grease with paper towel. In one case, when the hands-on workers had to seek assistance with the disassembly of a piston from the lab assistant at another station, all the males, both bystanders and administrators, followed the workers to the lab assistant's station. This left a group of five female students standing by the engine block for several minutes. None of them touched the engine block, instead they chatted about class assignments, suggesting that their inability to take on the hands-on worker role was not necessarily due to lack of opportunity.* (Hayward, 2004)

While this difference in confidence in hands-on skills is a concern, it did not appear to relate to the self-efficacy in using the CAE software. The instructor is aware of the issue and seeks ways to ensure that the learning environment in the machine shop is equitable. Where possible, no teams are formed with only a single female and the teaching assistants have been coached to encourage all team members to share all roles. In 2004 and 2005, the engineered components came from out-of-service equipment from a diverse range of industries. This provided a range of practical examples that were directly relevant to all four engineering programs.

Conclusions

Design engineering is a core focus in the engineering programs at the University of Guelph and there are four design courses that are common to all of the programs as well as program-specific design courses. The positive feelings of self-efficacy in terms general computer skills, CAE-specific skills and design engineering at the end of Engineering and Design II is encouraging. Although there has not been an opportunity to monitor the students in subsequent engineering courses, it is hoped that this foundation of confidence has been helpful in creating positive feelings about and satisfaction with the engineering program for all students and particularly for female students.

Given that there were positive findings for both males and females, the pedagogic changes appear to create an "inclusive" environment for all students. At the University of Guelph, the principles of "Universal Instructional Design" (http://www.tss.uoguelph.ca/uid/uidbrief.cfm) are recognised as useful guides when designing and delivering instruction to create classroom environments that respect and value diversity.

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