Enhancing Student Motivation and Efficacy through Soft Robot Design

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Abstract

This research paper evaluates student perceptual changes in engineering motivation and self-efficacy following participation in a soft robotics curriculum unit. Emerging from collaboration between researchers in the mechanical engineering department and technology and engineering education department at Purdue University, a novel design-based curriculum for student soft robot design has been pilot-tested at high schools this year. The present version of the curriculum materials is the result of previous years of pilot tests and refinement as we adapted laboratory procedures to a design- and inquiry-based lesson appropriate for classroom use. It is currently being implemented by seven high-school teachers using the Engineering byDesign curriculum. This paper will describe the rationale for the project and psychosocial factors underpinning the theorized utility of the experience for promoting student engineering self-efficacy and motivation. Following an overview of theory behind the curriculum, we describe how these principles align with the student experience while fabricating soft robots. Finally, we offer preliminary reports on initial states and changes in student perceptions as they participated in the curriculum.

Girls in STEM

Among areas of concern for technology and engineering education, is the participation of a diverse body of students [1]. For our field this includes female students, and a number of efforts have been made to understand factors related to this disparity [2, 3]. In middle-school and high-school, as students are often first exposed to these elective courses, interest begins to wane for female students [4]. One effort by Baker, Krause, Yaşar, Roberts, and Robinson-Kurpius[5] identified three factors related to engineering education which may impede student persistence—perceived societal relevance, tinkering self-efficacy, and technical self-efficacy—which have been the target of our developmental curriculum.

Societal Relevance

Initial images of engineering inaccurately represent the societal relevance: from the outsiders perspective, engineering is seen as an experimental science without understanding that there is an important intersection between science inquiry and human need [6]. Design, a core engineering activity, is also a social activity [7]. It involves cooperation among team members as well as interaction with clients and stakeholders.

Evidence suggests that these human-centered elements seem to resonate with female students when they are visible. In meta-analytic studies of interest, researchers found that there were predominant gender differences in “things” related and “people” related activities—with men showing greater interest in “thing” activities and women greater interest in “people” activities [8]. Similarly, they found differences in STEM related interest—again, a strong leaning toward males in science, mathematics, and engineering interest. “Gender differences of interest in various STEM fields can [also] be explained by the people-orientation and things-orientation of the disciplines” (p. 12)[9]; follow-up analysis of a variety of STEM disciplines showed a correlation between whether the occupation was things- or people-oriented and the percentage of females in the discipline [9]. For a familiar example in educational contexts, participation in engineering disciplines with clear connections to society such as environmental, biomedical, and biological and agricultural engineering exhibit a much greater proportion of female students (see Figure 1)[10]. Among student selecting engineering, there is evidence that this choice is at least partially based on perceived benefit to society [11]. The implications of these findings is that, while individual interests do play a factor in career choices, for girls the degree that a field is human interfacing affects their likelihood to participate and persist. Educational environments which leverage these interests may be better able to attract and retain female students [9].

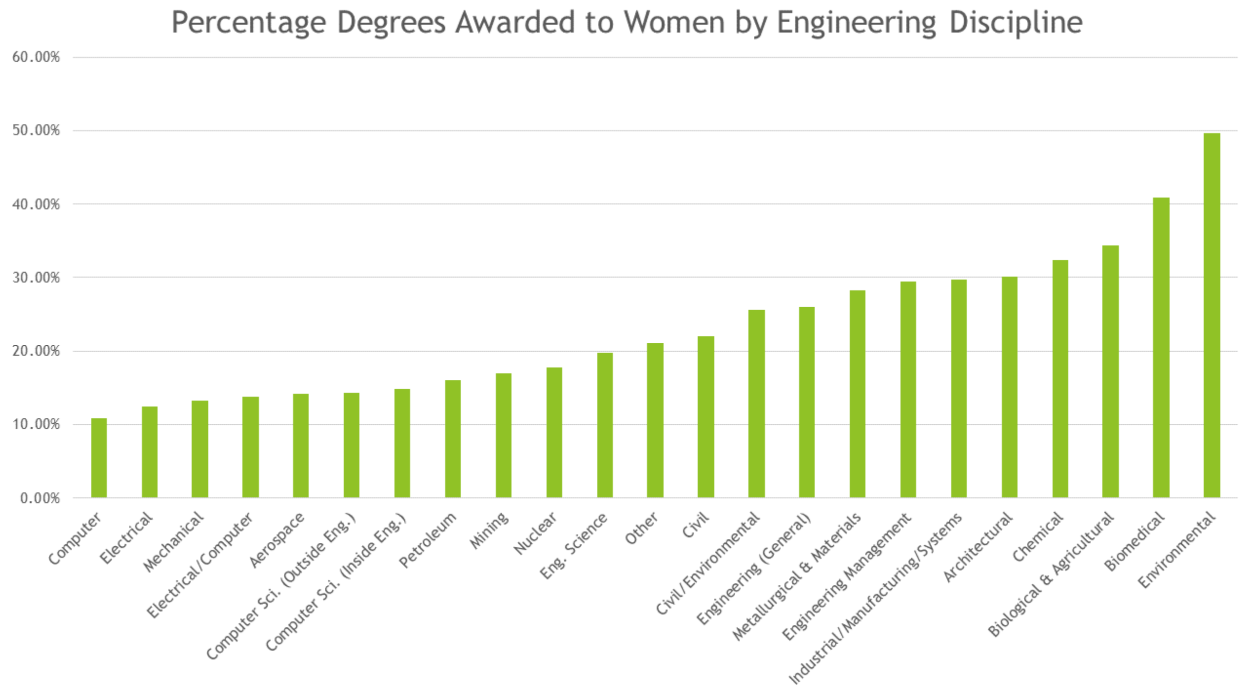


Figure 1. Percentage of degrees awarded to women in engineering disciplines. Adapted from Yoder, B.L. (2014). Engineering by the numbers. Retrieved from American Society for Engineering Education's College Profiles website: https://www.asee.org/papers-and-publications/publications/14_11-47.pdf.

Tinkering Self-Efficacy

Self-efficacy is an individual's self-perceived ability to accomplish a goal or task [12]. Self-efficacy is a domain specific measure—for example being confident in my ability to jump a certain distance says nothing of my confidence for gardening—with predictive relationships to relevant outcomes like motivation, effort, and persistence [13, 14]. Tinkering self-efficacy encompasses one's experience and comfort with manual activities [5]. Activities such as "manipulating, assembling, disassembling, constructing, modifying, breaking and repairing" (p. 3) [15] fall under tinkering self-efficacy beliefs. While these are recognizable as engineering activities, they are also gendered, with boys showing greater propensity to tinker in low-stakes circumstances [16].

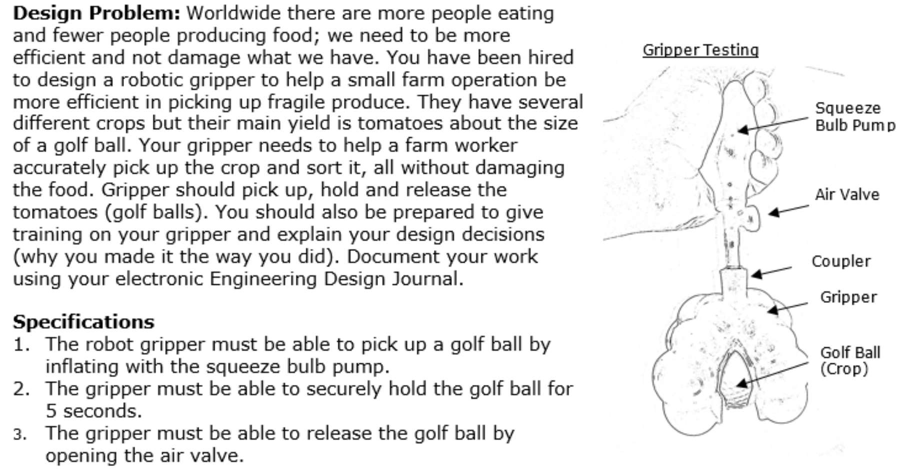
Accompanying the gendered nature of tinkering activities generally, specific materials can similarly carry gendered assumptions which impact student access [17]. Boys may handle tools and building supplies, such as wood or metal parts, more comfortably due to past experience, comfort with such manual activities, or considering themselves a “builder” [17, 18]. Ramifications of poor tinkering self-efficacy may include withdrawing from participation in activities that involve manual skills. Confidence with tinkering and exploration may be an obstacle to engagement when even informal interactions with learning materials may provide benefits.

Technical Self-Efficacy

Technical self-efficacy is an individual’s confidence to learn and apply technical content. In STEM related skills, where technical content is applied, female students often report lower estimates of their abilities. Gaps in problem-solving confidence [19, 20], math and science confidence [19], and design and creative confidence [21, 22] have been reported in prior studies. This gender difference can even persist despite high grades, showing that self-perception is a separate, important factor. Examinations of design teams have often seen girls relegated to planning and communications responsibilities on the project instead of technical aspects of the project [23]. If someone feels incompetent for a career it is unlikely they will pursue that path [24]; given the technical rigor of engineering this is especially important.

Intervening Through Soft Robotics Design

Aiming at these the psychosocial factors and through collaboration between the mechanical engineering department and technology and engineering education department, we have developed a novel soft robot design curriculum. The current version of the lesson engages students with an inquiry- and design-based challenge, given context by the design brief (see Figure 2). It has been adapted from previous outreach experiences [25] and refined through pilot testing with middle-school, high-school, and undergraduate students. Throughout the process we have received feedback from technology and engineering educators and students to inform our decisions. The cursory overview of the curriculum which follows does not enable us to describe all of the changes we have tried.



Design Problem: Worldwide there are more people eating and fewer people producing food; we need to be more efficient and not damage what we have. You have been hired to design a robotic gripper to help a small farm operation be more efficient in picking up fragile produce. They have several different crops but their main yield is tomatoes about the size of a golf ball. Your gripper needs to help a farm worker accurately pick up the crop and sort it, all without damaging the food. Gripper should pick up, hold and release the tomatoes (golf balls). You should also be prepared to give training on your gripper and explain your design decisions (why you made it the way you did). Document your work using your electronic Engineering Design Journal.

Specifications

1. The robot gripper must be able to pick up a golf ball by inflating with the squeeze bulb pump.
2. The gripper must be able to securely hold the golf ball for 5 seconds.
3. The gripper must be able to release the golf ball by opening the air valve.

Figure 2. Design brief for soft robot design curriculum including gripper demonstration sketch.

In the lesson students assemble a 3D printed mold to contain silicone rubber, the material for robot construction. The mold has a variety of configurations that allow design flexibility and investigation to see what works in certain situations. With this mold, students make a pair of soft robot "fingers" as a learning opportunity for the fabrication process and prototype for their eventual gripper design. The initial attempts at making fingers show that it is more complicated than it seems to be: a variety of design variables affect the functionality of the gripper and missteps in the manufacturing process can undermine its successful inflation. Students are given an opportunity to make more soft robot fingers with varied design, to investigate how the configuration of the gripper affects its actuation (curved movement) and make inferences for their completed gripper design. Finally, students make and test a completed gripper for assisting a fictitious farm operation harvest crops sustainably.

Throughout the curriculum experiences students document plans, observations and test results, and sketches of their work. These design notebooks also enable a final demonstration of their gripper and "training" on their gripper design in a class presentation. The lesson aligns with Standards for Technological Literacy 8 – 11 [26] and Next Generation Science Standards HS-ETS1-1 – HS-ETS1-4 [27], related to engineering design, modeling, and troubleshooting.

In addition to alignment with national standards, we feel that the design experience aligns with the psychosocial factors just described. First, for societal relevance, the design experience is intended to be human-centered, with an end user in mind. Supplemental materials in the curriculum also demonstrate an array of different uses for soft robotics, many in medical assistive settings. The soft nature of these robots is advantageous for human interaction compared to traditional robotics [28]. Next, for tinkering self-efficacy, the curriculum is designed to be iterative with failure framed as a learning mechanism. Student designs may not work the first time, or may not work how they hope, and can be improved upon by refining the mold design and manufacturing. The building materials are also substantively different than traditional robotics settings. Finally, for technical self-efficacy, the construction of soft robots draws on technical domains that have traditionally attracted female participation such as environmental engineering, chemical engineering, and biomedical engineering (since these are often bio-inspired or medically assistive; see also Figure 1). This fabrication process exchanges mechanical devices for chemical mixtures and reaction while remaining hands-on. We anticipate the changes in design and construction material and emphasis on iteration will promote student self-efficacy for engineering.

Present Research

The present research seeks to measure perceptions of STEM motivation and self-efficacy in the context of our soft robotics curriculum. Via the proposed intervention and alignment with the psychosocial factors described, we anticipate that participation in the curriculum will be related to increases in STEM motivation to increase self-efficacy. These findings report mid-year data based on beginning attempts at classroom implementation.

Participants and Design

For the pilot implementation of the curriculum seven high-school technology and engineering teachers in rural and suburban Maryland schools were identified as partners based on the recommendations of Engineering byDesign, a K12 engineering curriculum provider. In order to be considered for the study, teachers needed to have at least two sections of a 9th grade Foundations of Engineering class (sometimes called Foundations of Technology). The 9th grade curriculum includes a traditional robotic gripper unit and afforded the opportunity to have a quasi-experimental design: the control condition was the traditional robotics unit and the treatment was participating in the soft robot design lesson. Participating teachers had a range of experience, having taught between 4 and 25 years. Each teacher attended a professional development meeting where they participated in the curriculum in the role of a student and received all of the necessary materials for classroom delivery during the year.

Students were recruited in each participating teachers' 9th grade section, for a total of 30 sections this year (15 were taught during the 1st semester or throughout the year and are included in this report). Class sizes ranged from about 19 to 35 students; participation in the study ranged from 25.93% to 96.55% per course section. In the course of data cleaning, responses were matched on a pre- and post-survey (described further); the per-course percentage of students who completed both surveys was between 18.52% and 70.97%. Because the technology education course is a graduation requirement, we expected the gender ratio to be roughly equal. And among those reporting gender this was the case (53.28% female, 46.72% male).

Procedure

At the beginning of the course teachers informed students and parents of the study and collected parent consent forms and student assent forms. Participating students were given a random study identification number which was associated with the teacher and section for later analysis. As the introductory course proceeded, teachers delivered the hard robotics lesson (control) to approximately half of their classes (n = 6) and the soft robotics lesson (treatment) to their remaining classes (n = 9). Both conditions began at the same time and lasted about 10 periods (depending on external schedule conflicts that may have postponed any lessons). The robotics lessons began with participating students taking a pre-survey for motivation and self-efficacy, with non-participating students receiving an academic alternative activity. At the conclusion of the lessons students repeated the online survey.

Measures and Outcomes

The online survey used existing measures of situational motivation and engineering self-efficacy, as well as a question that identified student gender. The situational motivation instrument was the SIMS [29] which has 16 questions related to four constructs of motivation: intrinsic, identified regulation, external regulation, and amotivation. Each is measured on a seven-point scale according to whether the statement corresponded with the student's reasons for participating in the activity (*Corresponds not at all* to *Corresponds exactly*). Based on self-determination theory, each of these subscales is decreasingly self-determined [30]. A composite self-determination index was calculated where subscale means are weighted to the degree that they represent self-determined thinking: +2, +1, -1, and -2, respectively [31]. This composite score has shown high levels of reliability and validity in integrating individual sources of motivation into one variable for analysis in previous research [32]. Calculated from the SIMS instrument, the self-determination index will range from -18 to 18 with positive scores indicating greater self-determination.

Engineering self-efficacy was measured by the General Engineering Self-Efficacy Scale [33]. This contains five items measured on a 6-point scale of confidence to the activity (*Completely uncertain* to *Completely certain*). The items have demonstrated unidimensionality in previous work and significantly predicted academic success in engineering. The scale was correlated to intentions to persist, although this effect was masked by task values in predictive analysis suggesting that other factors play a role in long-term intentions.

Results

Eighteen responses were removed for nonresponse or significantly little variation in responses [34]. The remaining responses were screened for normality and proportion of missing responses; we concluded that the variables were normal (based on skewness and kurtosis values < |2|) and the degree of missing data was acceptable (< 2% for each question). Descriptive statistics for the received pre- and post-survey subscales are reported in Table 1, noting that 248 completed pre-test and 183 completed post-tests were available at the time of writing. Subscale reliability is reported using McDonald's *omega* reliability coefficient [35]. (Dunn, Baguley, and Brunsden[36] noted that in contrast to alpha reliability, omega does not assume constant contributions from all items in the scale and "performs at least as well as alpha" [p. 405].) Among these responses, 169 students had completed the pre- and post-survey; since this snapshot was taken during the year we expect many more matched responses to be completed in the coming months.

Table 1. *Descriptive Statistics and Subscale Reliabilities for Pre- and Post-Survey Subscales*

	Pre-Survey[a]			Post-Survey[b]		
Measure	*M*	*SD*	*ω*	*M*	*SD*	*ω*
Self-Determination Index	-3.69	6.57	—	-4.22	6.96	—
Intrinsic Motivation	2.59	1.47	0.92	2.64	1.57	0.93
Identified Regulation	2.89	1.53	0.87	2.81	1.56	0.90
External Regulation	5.30	1.59	0.83	5.54	1.39	0.79
Amotivation	3.28	1.46	0.72	3.45	1.63	0.81
Engineering Self-Efficacy	3.70	1.16	0.90	3.72	1.29	0.92

[a] *n* = 248. [b] *n* = 183.

Based on the descriptive statistics, any change in motivation or self-efficacy would likely be negligible, however two mixed design ANOVA tests were conducted to consider the effect of the soft robotics treatment, gender, and time on student motivation and self-efficacy. For each dependent variable (Self-Determination and Engineering Self-Efficacy) the test included between-subjects factors of Treatment condition (Hard or Soft Robotics) and Gender (Male or Female) with a within-subjects factor of Time (Pre- and Post-Survey).

Motivation Changes

The mixed design ANOVA for self-determination signaled a main effect on Gender and Treatment in the analysis, but these were due to overall differences in the groups and not related to the intervention. Taking into account motivation changes over time, we have not observed significant effects at this stage of the study (see Table 2). Following the analysis a Levene's test for homogeneity of variance across groups was conducted and insignificant, meeting ANOVA assumptions. In future analysis, F tests of interest are the test on the interaction of Gender and Treatment or any interaction effects with Time. Surprisingly, there is not a significant difference in motivation level by time based on these results.

Table 2. *ANOVA Reporting for Motivation Changes by Gender, Treatment, and Time.*

	df	SS	MS	*F*	*p*
	Between-Subjects Effects				
Gender	1	790	790.4	10.53	.001**
Treatment	1	341	340.5	4.54	.03*
Gender*Treatment	1	28	27.8	0.37	.54
Between-Subjects Error	165	12383	75.0		
	Within-Subject Effects				
Time	1	15.9	15.95	1.14	.29
Gender*Time	1	10.0	9.98	0.71	.40
Treatment*Time	1	54.1	54.12	3.86	.05
Gender*Treatment*Time	1	37.9	37.88	2.71	.10
Within-Subjects Error	165	2310.9	14.01		

*$p < .05$. **$p < .01$.

Self-Efficacy Changes

The mixed design ANOVA for testing self-efficacy changes was specified similar to the motivation model, with Engineering Self-Efficacy as the repeated-measures dependent outcome. Gender, Time, and Treatment were included as independent factors. There was an interaction effect for Treatment*Time with $p < .05$. Follow-up analysis showed that the mean for students in the hard robotics slightly decreased ($\Delta M_H = -0.1$) while the self-efficacy for the treatment group slightly increased following the lessons ($\Delta M_S = 0.2$). While there is a small effect for this interaction, $\eta^2 = .02$, the finding is promising for future iterations of the curriculum.

Table 3. *ANOVA Reporting for Self-Efficacy Changes by Gender, Treatment, and Time.*

	df	SS	MS	*F*	*p*
	Between-Subjects Effects				
Gender	1	0.1	0.14	0.06	.81
Treatment	1	0.2	0.16	0.07	.79
Gender*Treatment	1	1.0	0.96	0.40	.53
Between-Subjects Error	165	393.5	2.38		
	Within-Subject Effects				
Time	1	0.74	0.74	1.28	.26
Gender*Time	1	0.23	0.23	0.41	.53
Treatment*Time	1	2.36	2.36	4.08	.05*
Gender*Treatment*Time	1	0.05	0.05	0.09	.77
Within-Subjects Error	165	95.44	0.58		

Conclusion

In this research paper we have reported psychosocial factors related to female interest and persistence in STEM fields. In light of these factors, a robotics intervention has been developed where participating students fabricate soft, pliable robots which are novel and safe for human interaction. The curriculum is currently being implemented in high school classrooms, though preliminary data from the first iteration allows us to investigate the incipient efficacy of the curriculum. From the first iteration there do not appear to be effects on motivation. However, some self-efficacy effects have been observed as a result of participating in the soft robotics lesson.

A critical design of our research program is its classroom context. Given the wide range of experiences and impacts of classroom space, it can be difficult to isolate elements related to student growth [37]. However, preliminary data suggests some hope for future change based on the experience. There is a great deal of unexplained error across the student participants, which may be explained by other factors or covariates available. For example, the effect of teacher has not been controlled for here, and although we are not drawing comparisons about teacher efficacy, this could have a dramatic impact on student perceptions. Similarly, the teacher’s experience in implementing the soft robotics program may also be influential for student confidence. Our results have been collected from the first round of implementation and we know—as teachers and students are discovering—that successful soft robot fabrication is difficult. A number of manufacturing and design factors can affect the success of robotics, which may undermine the motivation and self-efficacy of students. These obstacles for student success need to be investigated and mitigated in future implementations of the curriculum.

Acknowledgements

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