Methodology for Studying Gendered Differences among Secondary Students’ Perceptions of Engineering

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Abstract

The causes of under-representation of females in engineering continue to evade the engineering profession. The literature contains many research studies investigating the reasons behind this under-representation, but no definitive causes have been determined. Another unexplained phenomenon is the non-uniform female enrolment across the different engineering disciplines, with disciplines such as chemical engineering having a higher female enrolment than mechanical engineering. We hypothesize that secondary students’ gendered perceptions of the engineering profession and education programs, the disciplines, the typical engineering skill set, and self-evaluation against this skill set partially explain the under-representation and non-uniform discipline subscription. This focus of this work, which is the first stage of this multi-stage project, was to design and validate a survey tool to test our hypothesis.

Introduction

Females are severely underrepresented within the engineering profession both in Canada and in the United States [1-3]. Unfortunately, since females are also underrepresented in engineering education programs [4, 5] (see Figures 1 and 2), the professional underrepresentation is likely to continue in the near future. Even worse, after decades of programs focusing on increasing female enrollment, we are actually seeing a decrease in female enrollment in Canada [4] and stagnated growth in the United States [5].

Figure 1: Canadian undergraduate enrollment of female students by discipline (2013) [4].
There is extensive research that attempts to explain this underrepresentation. The literature points to many potential reasons for underrepresentation, including perceptions such as the following:

- females seek to make social impacts, opportunities for which are not apparent to them in engineering [6].
- females prefer social challenges to technical ones [7],
- male dominated professions like engineering are unwelcoming to females [8],
- engineering curriculum is designed for a male learning style [9],
- engineering is a masculine profession [10],
- engineering companies have poor work-life balance policies [11],
- workplace discrimination exists [12],
- there is a lack of understanding of the profession [11],
- engineering is primarily construction work, outdoor work, working in a cubicle, and relating computers and machines, rather than people [11]
- females are less skilled in science and math, which diminishes female confidence (stereotype threat) [13-15],
- females have an inborn disposition for ‘caring’ or ‘humanities’ jobs [16], and
- female secondary students have lower self-efficacy and interest in engineering [17].

In addition to under-representation there is an unequal distribution of female enrolment amongst the disciplines (See Figures 1 and 2). Understanding what draws a higher percentage of female students to disciplines such as chemical engineering, may reveal strategies to increase female enrolment in other disciplines.

Within this multi-stage research project, we will use survey research methods to better understand the reasons for this under-representation. We hypothesize that one reason for the under-representation is the existence among secondary students of gender-specific perceptions.
of: 1) the engineering profession and education programs; 2) the differences among engineering disciplines; 3) the typical engineering skill set; and, finally, 4) a student’s self-evaluation in comparison to this skill set.

The goals of the first stage of this multistage project were to create a survey tool that: a) used inclusive language (especially around gender), b) minimized the amount of bias in the survey language, and c) was validated. The careful process undertaken in designing and validating the survey, including the consultation with multiple expert panels and cognitive interviews of students, are detailed in this paper. The survey tool was used to evaluate our hypothesis that there are three broad decision factors used by secondary students when considering whether to study engineering. These decision factors are: Perceptions – of the profession and the undergraduate programs, Achievement – to meet programs’ entrance requirements, and Confidence – self-perception of sufficient skills (See Table 1). The focus of the initial stage of the project was to design and validate a survey tool to answer, in subsequent stages, three research questions. Our first research question was to determine the level of importance that secondary students placed on each of these decision factors.

**Research Question 1: To what degree, if any at all, did these factors shape secondary students' decisions to apply to undergraduate engineering programs?**

<table>
<thead>
<tr>
<th>Decision Factors</th>
<th>Perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• of Undergraduate Engineering Programs</td>
</tr>
<tr>
<td></td>
<td>• of the Engineering Profession</td>
</tr>
<tr>
<td></td>
<td>• of different engineering disciplines</td>
</tr>
<tr>
<td></td>
<td>• of what skills are central to engineering</td>
</tr>
<tr>
<td></td>
<td><strong>Achievement</strong></td>
</tr>
<tr>
<td></td>
<td>• to meet programs’ entrance requirements in mathematics, science, and English</td>
</tr>
<tr>
<td></td>
<td><strong>Confidence</strong></td>
</tr>
<tr>
<td></td>
<td>• self-perception of sufficient mathematics, science, and English skills</td>
</tr>
</tbody>
</table>

The second research question was to determine whether a secondary student’s consideration of these decision factors was modified (influenced) by gender.

**Research Question 2: How are these factors affected by Gender?**

The third research question was to determine if a secondary student’s exposure to engineering or to engineers also influences (modifies) how they consider these decision factors. We also noted that the student’s exposure to engineering or to engineers would also likely be modified by gender (see Figure 3).
Research Question 3: How are these factors affected by Exposure (to engineers and engineering)?

Figure 3: Study model.

Survey Design

Our intention was to develop a survey to measure various decision factors in all three categories of decision factors, Perceptions, Confidence, and Achievement (see Figure 3 and Table 1). The questions about student perceptions of the engineering skill set will jointly measure their self-understanding of engineering, as well as measure their self-confidence in their qualifications to be an engineer. The questions about student perceptions of the engineering profession were designed to explore and measure the students’ explicit understanding of the engineering profession, and through analysing word choices, we set out to measure their implicit impressions.
(masculine/feminine, low/high status, etc.). The questions about the importance of decision factors will give us a better understanding of how secondary students rank the importance of various decision factors, and this understanding is ultimately vital for equipping engineering outreach programs to develop targeted recruitment materials and events to address the underrepresentation of females in engineering.

Student Perceptions of the Engineering Skill Set

A key objective of the survey was to capture participants’ perceptions of the typical engineer and compare those perceptions to their self-perceptions for the same descriptor set. Inspired by the origins of the BEM Sex Role Inventory [18], we set out to develop a complete list of descriptors that the general public typically associated with engineers. In order to avoid the resource cost of conducting a separate study just to generate this list of descriptors, we explored several sources from existing tools. The challenge was to find a tool with well-established, pre-existing literature defining the typical engineer personality. The sources explored were: Raymond Cattell's 16 Personality Factors (16PF) [19], Big Five Personality Traits [20], Multidimensional Personality Questionnaire (MPQ) [21], and a values list organically created over years of workshops hosted by an in-house leadership organization. In the end, the Big Five Personality Traits, MPQ, and the leadership values list were rejected as sources of engineering descriptors because none had encompassed well-established, pre-existing literature for defining a stereotypical engineering personality. 16PF did have limited literature on describing the stereotypical engineer using its descriptors [22, 23], but the ability of the tool to differentiate between genders had not been established [24-26].

After a careful review of these valuable sources, we decided to try a different approach. Engineers Canada has a list of attributes all engineers graduating from an accredited engineering program must possess [27]. We used these 12 graduate attributes to derive 13 skill descriptors written in layman’s terms. For one of the 12 graduate attributes an appropriate skill description was not readily apparent. For two other graduate attributes, multiple skills were needed to fully describe the attribute (see Table 2). A major benefit of this process was that there is solid agreement within the profession that these skills represent a stereotypical engineer.

Table 2: Engineers Canada Graduate Outcomes and the Derived Survey Skills

<table>
<thead>
<tr>
<th>Graduate Outcomes</th>
<th>Survey Skill</th>
</tr>
</thead>
<tbody>
<tr>
<td>A knowledge base for engineering</td>
<td>Good with Technology</td>
</tr>
<tr>
<td>Problem analysis</td>
<td>Problem Solver</td>
</tr>
<tr>
<td>Investigation</td>
<td>Curious</td>
</tr>
<tr>
<td>Design</td>
<td>Likes to Make Things</td>
</tr>
<tr>
<td>Use of engineering tools</td>
<td>-</td>
</tr>
<tr>
<td>Individual and team work</td>
<td>Leadership</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------</td>
</tr>
<tr>
<td></td>
<td>Team Player</td>
</tr>
<tr>
<td>Communication skills</td>
<td>Well Spoken¹</td>
</tr>
<tr>
<td>Professionalism</td>
<td>Respected</td>
</tr>
<tr>
<td>Impact of engineering on society and the environment</td>
<td>Socially Conscious Environmentally Conscious</td>
</tr>
<tr>
<td>Ethics and equity</td>
<td>Honest</td>
</tr>
<tr>
<td>Economics and project management</td>
<td>Organized</td>
</tr>
<tr>
<td>Life-long learning</td>
<td>Likes to Learn</td>
</tr>
</tbody>
</table>

1: The phrase “well spoken” was intentionally used to ensure the readability of the survey for secondary students. This is a phrase that is commonly used to indicate effective communication skills. In future iterations we will include the phrase “effective writer” as an additional indicator.

Student Perceptions of the Engineering Profession

Similar to the initial plan to measure student perceptions of the engineering skill set, we planned to measure perceptions of the engineering profession using a list of occupational descriptors derived from the Campbell Interest and Skill Survey [28] - a tool used for career planning. However, Campbell’s knowledge as well as our own knowledge of what secondary students think about engineering was limited. As such, we decided to use a qualitative exploratory approach and simply used text fields to ask the students, “What are the first three descriptive words or phrases that come to mind when you hear Engineer? Be honest and don’t over think it.”

In an effort to identify if differing secondary student perceptions were a factor in the large discrepancy in female enrollment between disciplines, this question was repeated three times, but with Chemical Engineer, Mechanical Engineer, and Civil Engineer specified. For example, “What are the first three descriptive words or phrases that come to mind when you hear Mechanical Engineer? Be honest and don’t over think it.” These three disciplines were selected because they are three of the original, long-standing, engineering disciplines with vastly different female enrollments. Chemical engineering had high female enrollment, mechanical engineering had low enrollment, and civil engineering was in the middle [4,5].

Once this qualitative data was collected, the plan was to do a word frequency analysis of the responses and then use this data to devise a shorter, more focused descriptors checklist for a future revision of the survey.
Engineering Decision Factors

The decision factors question is potentially the most immediately useful for those seeking to effect female enrollment in engineering. Through discussion and the literature review, a list of possible decision factors was generated. For instance, some literature indicates that females perceive engineering as a lower status profession than other professional degrees such as medicine. Therefore, we asked the students if their desire to be part of a respected profession was a decision factor. If students indicated that they used a decision factor in their own decision process, then they were asked to indicate its importance. Since one immediate goal was to potentially use this information to target recruitment materials and programs, knowing the level of importance is highly valuable for enabling us to target the areas that would have the greatest impact for attracting females into the engineering profession.

After the initial running of the survey an expert panelist gave a suggestion to streamline this question by removing two of the initial seven options, while keeping all the important data.

Expert Feedback

Once a complete draft of the survey was written, feedback was sought from multiple expert panels. The expert panels who contributed feedback included: 1) Engineering Education Researchers Group, 2) Engineering Education Graduate Students, 3) Education Graduate Students, and 4) Engineering Undergraduate Students. Additionally, cognitive interviews requiring participants to think aloud as they answered the survey questions were conducted with three individuals with a similar profile to the participant pool. Their feedback that either initiated significant changes to the survey or that generated significant discussion is discussed below.

Engineering Education Researchers Group

The survey was sent to select members of this group, and feedback was returned by three members.

Gender: Since gender modified perceptions are a primary aspect of this survey, the gender demographic question is critical. The wording for several other demographic questions were based on questions asked in the local school board student survey so that we could utilize language familiar to the students. Unfortunately, the gender question for the school board survey was not a good exemplar since it was not inclusive of non-cisgender individuals. The draft of the question was therefore modeled after various other inclusive surveys. This meant allowing for a spectrum of gender identities without being overwhelming. One exception was that rather than use the technically accurate man or woman gender identification, we used male or female. While technically this is a measure of sex and not gender, we felt it was necessary to maintain similar language with already existing surveys. One member felt strongly that we should be using the technically accurate terms. We did not change the survey and instead decided to revisit the question after the initial implementation of the survey.
Deceptive: A member expressed concern that while the focus of our research questions was on studying gendered perceptions, in the survey we simply tell participants we are measuring students’ perceptions. The member felt we were being unnecessarily deceptive with the participants. We did not change the survey because some research suggests that informing female students that gender differences are being measured affects how females respond [13-15]. While these studies [13-15] were primarily dealing with performance-based questions rather than perception-based questions, the researchers felt that the risk of deception was not severe enough to expose the survey to this potential source of error. Our survey with the slight deception had also passed ethics approval.

Sexuality: In an early iteration of the survey, participants were asked to self-identify their sexuality. Care was taken to design this question to be inclusive, but concerns were still raised, primarily because of the plan to have parents of the participants sign the letter of consent. In this process it was reasonable to expect that parents may read a completed version of the survey. It was also reasonable to expect that participants in this age group may be questioning their sexuality, but may not have yet discussed this with their parents. Since measuring trends in perception based on sexuality was never a primary goal of the survey, it was deemed that the benefits were not worth the risk of prematurely exposing students who may not have come out.

Engineering Education Graduate Students

Two members of the Engineering Education Graduate program returned feedback on the survey.

Literature Review: One member suggested for the addition of many excellent articles to the literature review, and all of these were included in the final version of the paper.

English Bias: A graduate student with experience teaching at the secondary level pointed out that he anecdotally noticed in his own surveys a bias towards answering English as the language most often spoken at home. He speculated that students, for whom English was a second language, may fear being placed into what they may have perceived to be undesirably ESL streams. No changes were made to our survey, but this was noted as a possible source of error.

Education Graduate Students

An early study model was brought to a survey research graduate class for discussion. Based on their suggestions, we acknowledged that exposure should be considered as a modifier and subsequently added the third research question to our survey.

Engineering Undergraduate Students

Two senior undergraduate students were asked to give feedback on the survey. Their major comment was to shorten the survey in order to improve the sustained engagement of participants.
Cognitive Interviews
Cognitive interviews were conducted with three individuals with profiles similar to the expected range of profiles in the participant pool.

Subject 1: This subject is a male, 2nd-Year Biomedical student who originally considered engineering but decided to study life sciences instead. The individual is located outside of the city where the study was to be conducted. His comments led to the streamlining of the self-reported academic grades question, where unnecessary bubbles were removed, the term “learned” was clarified with regards to the frequency of exposure to engineering in school, and phrases in the About Engineering questions was included. A major comment was that the racial backgrounds and languages were specific to the city where the survey was to be conducted. If the survey were to be used outside that city, then a more national list should be used such as that found in Statistics Canada surveys.

Subject 2: This subject is a male, 4th-Year kinesiology student who never considered engineering. His major comment was that participants might have concerns about isolation due to gender not only in the workplace after graduation, but also while studying in the program. This concept was added as an additional decision factor.

Subject 3: This subject is a female, 4th-Year music education student who considered engineering. She suggested clarification of the survey questions that involved graphical arrows to direct participants to the appropriate next question.

Pilot

A local private secondary school was selected for the initial administration of this survey because of close proximity and shorter approval process times. After receiving approval from the school administration, we presented the study to the school science department (as suggested by the administration). All teachers were supportive of the survey in general, but only one was willing to allocate class time to completing the survey. This teacher taught two grade 12 advanced placement physics courses. Administering the survey to a grade 10 career studies class is planned, but it has not been completed at the time of the publication.

In parallel to the process of obtaining school approval, the approval from the university ethics board was also obtained with no changes required.

The selected school had advantages, but also some distinct limitations. As an advanced placement physics course at a high achieving private school, the participant pool does not provide a representative cross-section of the general secondary school populace. Therefore, the results are not generalizable to the general population. This coupled with the small participant pool meant that only descriptive statistics will be used in the analysis of this initial survey data.
Another limitation was the unusual level of exposure to engineering. The high school physics teacher and another science teacher at the school were both female engineers, a fact known and discussed by the students in class.

On two separate days, we attended the two classes. We introduced ourselves as engineering faculty and that we research diversity in engineering. We then delivered presentations on engineering-related physics that related to their curriculum. At the end of our presentation, we distributed a paper survey with instructions to: 1) have their parents sign the cover page consent letter, 2) sign the cover page consent letter themselves, 3) complete the survey, and 4) return the survey to their teacher.

We collected the completed surveys from the teacher two weeks after our in-class presentation. Once the two permission signatures were verified, the cover page was removed from the survey and destroyed (to protect student privacy). This rendered the surveys anonymous.

**Pilot Preliminary Results**

The survey population was approximately 50 students spread across two classes, grade 12 advanced placement physics at an elite private school with close affiliations to a local university. The response rate was over 50%, with a respondent sample of 27 students. There was an underrepresentation of female students in the population, approximately 20%, but over 50% of the respondents in the sample were female (14 female and 13 male respondents). This was ideal for studying gendered perceptions, but in itself may reflect some gendered perceptions of the importance of this area of research. If male students were not inclined to take the survey as seriously as female students, that could affect their answers. This was indicated in at least a couple of the responses. One male student with low quality responses (significant use of ‘ditto’ marks instead of individual answers) indicated that his choice not to study engineering was entirely financially motived with repeated comments such as “no 7 figures” (indicating he would not make a salary in the millions of dollars as an engineer). Counter to that a female respondent with highly detailed and thoughtful answers expressed an appreciation for this area of research, “Power to more women engineers for working to break down social conventions.”

With a small sample of 27 respondents we will not be able to use statistical analysis, but instead we will use descriptive statistics. Additionally, due to the rather unique demographic of the students, the work will not be easily inferred for a general population. Academically elite female students, with a highly educated family background, who have opted to take an advanced physics course, seem to be ideal candidates to study engineering. Yet preliminary results showed that only 21% (3/14) had decided to study engineering. We still had a chance to recruit four more of the female students who were undecided; however, 50% (7/14) of the females had already decided against engineering as a possible profession. Of those seven female students, five indicated a strong interest in pursuing medicine.
Conclusions

After a thorough development and validation process, a detailed survey tool was designed to gain a better understanding of what decision factors are involved when secondary students consider engineering as a possible post-secondary education pathway. This tool not only measures these decision factors, but also collects additional data to examine if gender and exposure to engineering modify these decision factors.

The next step will be to analyse data collected in the pilot. This analysis will be used in two ways. 1) Based on the analysed data, a debrief of our observations, and additional expert feedback, we will revise the survey, convert it to an online format, and seek a larger participant population. This will allow us to do more detailed statistical analysis and potentially infer the results to a greater population. 2) This analysed pilot data will be presented back to the original participants. Hopefully we can convince those four undecided female students to enroll in engineering in the fall, and maybe even attract the other seven females to reconsider helping us to engineer a better world.

Reference