2018 ASEE ANNUAL CONFERENCE & EXPOSITION
125 YEARS AT THE HEART OF ENGINEERING EDUCATION
JUNE 24–27, 2018 SALT PALACE CONVENTION CENTER SALT LAKE CITY, UT
Paper ID #23577

From Physics to Where? Diagnosing the Effect of a Discovery-based Teaching Paradigm on Continued Barriers to Women's Entry to the Physical Engineering Science Professions (RTP, Diversity)

Prof. Katherina V. Tarnai-Lokhorst, Camosun College

Katherina Tarnai-Lokhorst, P.Eng., BASc, MBA, doctoral candidate

Kathy is a Mechanical Engineering Instructor at Camosun College and Adjunct Professor at the University of British Columbia. She received her BASc from UBC in 1987 specializing in aerodynamics and her MBA from the University of Phoenix in 2007. Kathy is pursuing her Doctor of Social Science at Royal Roads University, researching educational philosophies and practices prevalent in high school and introductory university physics and math courses, and developing recommendations to increase gender diversity in engineering education and the engineering profession. Kathy is the elected Vice President for Engineers and Geoscientists British Columbia, and has served on several educational, policy and governance boards.

From Physics To Where? Assessing the effect of a discovery-based teaching paradigm on reducing gender barriers to engineering
(RTP, Diversity)

ABSTRACT: Girls and boys participate equally in Physics 11 classrooms in the Greater Victoria Region in British Columbia. Yet girls continue to comprise less than 20% of Physics 12 classrooms and less than 15% of most engineering education programs. This active research focuses on diagnosing and mitigating the invisible barriers in Physics 11 that preclude young women from continuing their studies in physics to the 12^{th} grade and beyond. Three identified factors for the persisting gender gap in physics follow. The first factor is rooted in stereotypical beliefs about engineering as a gendered career. The second factor arises from student beliefs that there is little new to discover in physics. The third factor relates to an inability to visualize how physics applications can make the world a better place.

This paper presents an alternative to additive outreach programs prevalent in universities and engineering societies. The proposed teaching paradigm is demonstrably simple to implement, eases teacher workload, enhances student learning and creates a significant improvement in perceptions and beliefs about self-efficacy in physics, an indicator of student success and motivation. The research identifies an unanticipated impact of introducing engineering design principles into Physics 11 classrooms. Physics 11 teachers participated in developing a lesson plan that guides facilitators of learning through the discovery- or inquiry-based activity. The mixed methods research methodology included surveys, observations and interviews to generate data testing the hypothesis that connecting physics applications to scenarios derived from the students' life experiences enhances girls' understanding of the social benefits attainable through engineering design. The resulting teaching paradigm uses team-based, project-based learning techniques that create knowledge using processes directly applicable to engineering. The findings demonstrate trends indicating that male students may also increase in self-efficacy using this paradigm. This paper outlines the generalizable lesson plan and teaching techniques, and examines the unexpected outcomes citing numerous relevant peer-reviewed studies and reports.

Introduction

Engineering persists as a female-deficient profession in North America. In Canada, women comprise 12.8% of the engineering population and 20% of enrolment in engineering programs [1]. Organizations from non-engineering professions that achieved gender diversity over the past five decades cite greater employee satisfaction, lower turnover, higher productivity and greater financial success than professions with gender unbalance like engineering [2]–[6]. During this period, therefore, many universities, colleges and engineering societies developed science camps, clubs, workshops and presentations to educate and excite youth about the potential for careers in engineering and physics [7]–[9]. Although these activities rely on parents and teachers to add these extra-curricular activities to children and youth schedules, the past years demonstrate their success in retaining girls in mathematics and physics: girls make up 50% of physics classes in the 11th grade [10], [11]. Yet, more than half of these girls do not persist through to Physics 12 or post-secondary education in engineering or physics [12], [13].

This research tests the hypothesis that student self-efficacy and their perceptions of physics and engineering as viable career options can be enhanced by introducing the intersectionality of engineering, student experience and context-based applications of physics into Physics 11 laboratory settings [14]. Studies indicate that all learners, male and female, may achieve greater academic success through the practical application of theory [15], [16]. In order to avoid the zero-sum perspective often anticipated in gender initiatives [17], the desired increase in the participation of women in this research is in addition to that of men [18].

The research vision is to eliminate the perception of engineering as a gendered career by inspiring all youth with science abilities to pursue engineering disciplines. The new curricula enriches physics knowledge acquisition by applying physics concepts to situations students define from their own life experiences, forming direct connections between the applications of physics and making the world better in some way. Studies show this sense of purpose especially appeals to women as a motivating work outcome [19]. The research tests whether in-class activities that emphasize the practical dimension enhance self-efficacy and, as a result, increase girls' interest in a future career that applies physics. The research outcome indicates surprising trends in boys' beliefs and perceptions of increased self-efficacy and sense of belonging in the physics classroom.

Diagnosing invisible barriers to female high school physics students

Young women occupy an increasing percentage of the seats in high school physics classrooms yet they do not, for the most part, enter post-secondary programs in the physical engineering sciences or physics [10], [20]. They cite reasons including three of particular interest to this research: they do not feel they belong in the physics classroom, they have the impression that there is nothing new to discover in physics and they cannot see how to use physics to make the world a better place [10]. The first reason stems from social factors, unintended implicit bias and precluded interest [21], [22], which can be addressed through education and training [23]. The second two reasons may be addressed through the new teaching paradigm introduced in this paper.

The first female engineers earned their degrees in the early 20th century. Industry actively recruited women to engineering-type occupations during the two world wars and women's participation continued to increase regardless of subsequent marginalization [24], [25]. Still, the majority of young women with high school physics credits today persist in making gendered career choices in spite of the advances of feminist influences on society and on curriculum [10], [20], [26], which resulted in increasing female participation in other professions like law and accounting [27]. Some authors suggest gendered career decisions arise from differing interests between men and women [28] but others suggest it is more likely that, when interpreted against the backdrop of social change and the historical capabilities of women in technical fields, this phenomenon may be attributed to unintentional persisting sex discrimination by practitioners and educators [29]–[33].

The ongoing debate about the benefits of mixed- versus single-sex classrooms on gender bias and student learning is not a focus of this paper. Instead the research focus is on the teaching paradigm. Most scholars agree that teaching methods that incorporate practical experiments encourage girls to be more creative with their hands and help them to better connect with the physical sciences regardless of classroom composition [34]. Mixed-gender classroom studies demonstrate that boys tend to assume the more active roles, a role behaviour that is observed as early as kindergarten [9]. When girls are left to take on the passive role of note-taker, however, they disengage from the lessons and lose both confidence and interest in STEM (science, technology, engineering and math) [35]. In the research activity, students worked in self-selected small groups with varying compositions. In other words, this study may isolate the confounding impact of classroom composition by permitting students to work with peers of their choice.

Physics education in BC

Engineering education in Canada is provided by publicly-funded universities, colleges and institutes and is mandated by the Provincial governments. British Columbia is the westernmost province with a population of approximately 4.6 million people, doubled from 1972 [36]. Five of the fifteen publicly-funded colleges and eleven publicly-funded universities offer engineering diplomas and degrees, and four offer comprehensive post-secondary training that includes courses transferable to other engineer programs. Privately-funded colleges and universities in BC have narrower mandates than public institutions and do not provide nationally accredited engineering education.

High schools in British Columbia provide opportunities for science education through elective courses in the 11th and 12th grades . Until the 10th grade, high school science is a required course topic for students intending to pursue post-secondary education and combines the disciplines of biology, chemistry and physics [37]. Most post-secondary programs require two Grade 11 science courses; engineering programs typically include Physics 12 in their list of prerequisites.

A significant percentage of girls and boys choose physics as one of their high school science electives. Regardless of motivation, whether simple interest, ease of course work, academic focus or career pursuit, the successful completion of Physics 11 serves to indicate a capacity for engineering. Girls in British Columbia continue to participate roughly equally with boys in Physics11 classes and exhibit equally successful rates of completion. In the Victoria region, as indicated by the research sample population, girls comprise over 50% of the Physics 11 classrooms but only 20% of Physics 12 classrooms [38].

Demographics in BC Physics 11

The participatory action research team consisted of five Physics 11 teachers from the Greater Victoria region. The participants had between 17-31 years teaching experience and represent public and independent (private) schools. Their students became the study group and completed surveys to record their beliefs and perceptions before and after the in-class research activity. Overall the student sample sizes pre- and post-activity were very similar. The pre-activity survey sample consisted of 250 respondents of which 21 were missing data (did not self-identify as male or female) leaving a total of 229 valid units. Gender in this study is considered binary because insufficient units existed in cross-tabulated categories for statistically significant results when including non-binary gender classifications (categorized as "missing" data for the purpose of analysis). The pre-activity sample population was 53.7% female. The post-activity sample consisted of 224 individual responses of which 6 were missing data leaving a total of 218 units. The post-activity sample population was 51.8% female. The online deployment resulted in 71 responses of which 23 were missing data leaving 48 valid units. The online sample population was 62.5% female. The online deployment resulted in too few data points for generalizable analysis.

Engineering design teaching paradigm

The long term use of dated apparatus, such as acceleration timers with ticker tape to measure changes in velocity or spring scales to measure force, potentially constructs perceptions that physics is old and unchanging, with nothing new to learn [39]–[41]. Such beliefs may be dispelled by ceasing to use the same experiments that have been part of the curriculum for more than six decades. This research project developed an interactive activity around the fundamental physics concept of friction, enabling the application of physics in contexts from the students' own experiences.

Research activity

The greatest change proposed and eventually implemented relates to the teaching process and how the teacher-facilitator presents the physics concept. In the pre-existing paradigm, teachers introduce the theory of a new concept prior to running an experiment or discussing contextual applications of the theory. The physics laboratory objective is solely to verify or support the presented theory. Teachers then encourage students to extrapolate implementation contexts through discussions that follow the lab experiment. The focus of the student lab report is on theory, procedures, data collection and applying that data to the theoretical equations. Report conclusions recount how well the experiment matched the theory by expressing the experimental results as within a specific percent error from the expected theoretical result. While this process is necessary for reinforcing the rigorous scientific method of theoretical proofs, it involves little creativity, individual play or personal input.

The new process flips this paradigm to begin with a discussion of context through which students identify potential experiment scenarios from their life experiences (Figure 1). The students then consider how the concept might be modified within their chosen scenario. The students must imagine and design ways to improve the current situation or produce a preferred state within the situation by changing a single physical parameter. This allows the students to develop theoretical expressions during the experimental design and verification phases. The activity wraps up with reflections by the students' on their individual and team learning. The report becomes a presentation of their ideas, their experiment design, their expected outcomes and their findings, all related to the real life scenario with which they began. (Figure 2).

Through the experiment phase, the teachers endeavour to constrain their contributions to a purely supporting role, limiting their input to providing assistance in finding tools and materials to construct their prototypes, guidance on recording experimental data, advice on detailing or dimensioning sketches, and to prompting the development of theoretical mathematical expressions that relate input to output measures. In this way, teachers maximize student engagement and creation of physics knowledge, building on what was learned in previous classes. The purpose of this method is to allow students to play with applying physics knowledge in new relatable ways. The small groups report on their work by answering discussion questions designed to guide their reflection on both the process and the learning they acquired (Figure 2). In the final phase, which may occur in a following class period if the cohort needs more time during the session for their team work, the teacher facilitates a large-group discussion of the outcomes, generating

Figure 1: Facilitating the discussion on student-based contexts. Foreground: simple lab table prep.

relevant mathematical expressions to enable future theoretical applications. This discussion occurs in the larger group to reinforce shared knowledge creation.

Outcomes of research

The qualitative outcomes, determined through interviews with the teachers following the activity, indicate that the activity increased student participation across the full classroom, all genders. Students identified as typically passive observers participated more actively in all stages. The teachers expressed interest in the "flipped" way of teaching: couching the concept within the context instead of offering contextual examples after a prescriptive experiment and analysis. They stated a preference for and would use again the open-ended questions and the facilitation methods employed to prompt students in coming up with their own experiences as examples.

The practical experience of ideation, developing their own scenario, creating the data tables and designing the experiment to verify theory increased students' comfort in solving physics problems and increased the engagement of both female and male students who previously would not participate in classroom activities. The quantitative survey results indicate trends in several key outcomes including the elimination of differences in the students' perception of destiny and control across several questions. Although these questions do not overtly relate to physics, they elicit responses within the context of physics. Several questions relating to destiny and control, for example, returned statistically significant differences between female and male responses that were eliminated following the activity:

- "There will always be wars, no matter how hard people try to prevent them."
    - Pre-activity survey resulted in two degrees of freedom, df=4, and a Pearson Chi-Square value of X^2=24.497, well above the required values for four degrees of freedom of 14.86 (α=0.005), rejecting the null hypothesis that no change exists.

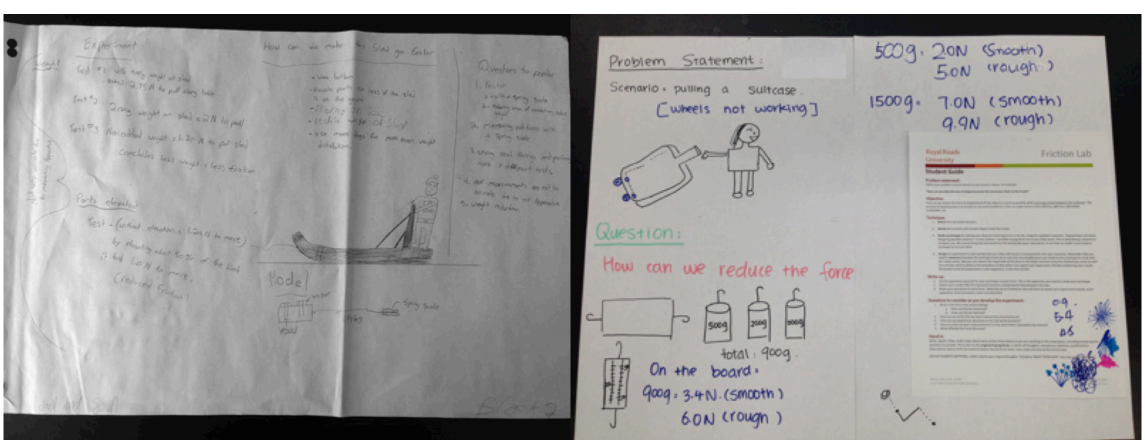

Figure 2: Samples of student output. The process: step one, discuss and select scenario; two, draw scenario; three, create prototype for verification testing Second image, the suitcase example, includes the Student Guide, which this group followed closely.

- "The world is run by the few people in power, and there is not much the little person can do about it."
  - Pre-activity survey resulted in two degrees of freedom, df=4, and a Pearson Chi-Square value of X^2=10.760, above the required values for four degrees of freedom of 9.490 (α=0.05), rejecting the null hypothesis that no change exists.

Probing more closely, trends were observed, indicating male students' agreement with the following statements decreased:

- "Many of the unhappy things in people's lives are partly due to bad luck." (α=0.10):
- "No matter how hard you try, some people just don't like you." (α=0.10):
- "I have often found that what is going to happen will happen no matter what." (α=0.25):

Overall, these results are unexpected, both the qualitatively noted increase in participation in the classroom and the quantitatively increasing trend in the perception of control by male students: the result is contrary to results from earlier studies in Physics 11 classrooms, which indicate that female students exhibit a lower sense of belonging and self-efficacy than their male classmates [42], [43]. However, this research outcome may be explained by considering that the participatory action research team conducted their educational workshop and activity development prior to the start of the term, two or three months before the activity occurred in their classrooms. Of note is the high responses to these questions by female students indicating their existing and persisting sense of belonging and comfort in the classroom, before and after the activity. It is posited, therefore, that the teachers may have changed their behaviour from the previously established norms [10] and favoured female students in their classrooms more highly by spending more time with them and ensuring girls' questions be fully answered. In other words, by focusing so much on the girls in their classrooms, the teachers may have inadvertently increased girls' sense of belonging while decreasing the boys' sense of belonging, an effect which was eliminated by the research in-class activity. The conclusion may be that the engineering design based activity effectively elevates the inclusion and self-efficacy of all students. Further targeted research may identify whether this is the case.

Conclusions

The relationship between societal beliefs and gendered career choices is becoming clearer: the analysis of data from a subset of the British Columbia (BC) school system presented in this paper indicates curious tendencies in relationships between the choices students make in high school, the abilities of high school students and their subsequent choices for post-secondary education. This research project tackles the low registration rates of women into physics and engineering education programs by focusing on Physics 11 as a key course in which young women evidently make a decision not to pursue engineering [10].

The in-class activity qualitatively resulted in higher participation of both male and female students in the physics activities. All students demonstrated increased comfort in using physics and greater ability to visualize innovative applications of physics that make their world better. The quantitative results indicate trends in dispelling gender differences in their perceptions of their destiny and control in the physics classroom and trends of increasing male students' sense of belonging in the physics classroom. Female students' exhibited high sense of belonging persisted. Whether the changes persist and influence their post-secondary educational choices can only be determined through longitudinal research.