Using inquiry-based learning in engineering statistics courses

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***Abstract*—Many engineering students struggle with a first course in statistics. One of the reasons for this is that statistics differs from "traditional" mathematics curriculum, such as calculus and differential equations. Merely giving students problem sets does not teach them to think in a particular fashion, as statistics problems require the assimilation of more varied information than using formulas or even applying those formulas to situational (story) problems to solve for a particular variable or variables. Data rarely conforms to contrived values, so the student's ability to critically think and make decisions is of paramount importance. Since statistics is different from a traditional mathematics discipline, we feel it is necessary to differentiate instruction from a traditional mathematics class. Because statistics and data science requires considerable decision-making processes and analytical ability, we feel that elements of inquiry-based learning will be beneficial to students. These inquiry-based lessons will be provided in the form of POGIL, or Process-Oriented Guided Inquiry Learning, activities designed to lead small groups of students through specific material within a specific subject domain.**

Keywords—statistics education; POGIL; inquiry-based learning; engineering education

I. Introduction

As the world that surrounds us becomes more and more reliant on technology and data, students of engineering are finding themselves in situations where they need more than the classical mathematics education which consists of algebra, trigonometry, calculus, differential equations, and perhaps linear algebra. Many engineering students now find that they are required to take one or more statistics courses in addition to the traditional mathematics courses. An existing body of research shows that students tend to struggle with the concepts and interpretations that are taught in statistics courses [1]–[3]. Generally speaking, statistics is not one monolithic subject, rather it is a conglomeration of different topics and skills, such as algebra, calculus, computer programming, data modeling, and critical thinking.

Because of the necessity of an interdisciplinary approach, learning statistics can be very difficult for students. Not only is statistics a very broad subject, each dataset is different, thus making a formulaic approach to learning (e.g. repetition via homework assignments) very difficult. Considering the fact that statistics as a subject does not fit into one particular "box," we theorize that standard lecture-based instruction may not always be the best method to teach students the subject with the appropriate breadth and depth necessary to give them adequate proficiency.

II. Theoretical Framework

In the early part of the twentieth century, renowned mathematician Robert Lee Moore devised a method of instruction, aptly called the Moore Method. The Moore Method is perhaps one of the earliest records of inquiry-based learning and at the beginning of a course consisted of students being given very simple mathematical statements to prove at the chalkboard in class. If the student could not produce a proof, the class was consulted to help, and eventually a valid mathematical proof was produced. The instructor was often only an observer and never lectured on the class topics. Instead, he simply posed questions and facilitated the discussion in the student-centered classroom. Moore felt that "[the more] the students discover for themselves the mainstream of the subject, the more [Moore] became convinced it not only could be made to work but that it would also be attractive to students" [4, p. 274].

Moore's innovative teaching method proved to be excellent for creating research mathematicians [5]. In its pure form, however, it is difficult to implement today. With the advent of instant information via the Internet, much of the discovery process of this type of learning can be lost. This lead to various modified versions of Moore's Method, some of which divide students into working groups as well as provide more instructor interaction with the class. Research has been done with modified versions of the Moore Method, and success has been reported with individuals who believe they had a richer experience and interaction with mathematics because of the course format [6].

While different versions of the Moore Method are commonly used in pure mathematics classes, they may not be appropriate to teach statistics because they are based on developing proofs for theorems in a logical progression. Statistics is a far broader subject area and likely requires a different learning methodology for students to understand the bigger picture. A more appropriate set of activities for engineering students to learn statistics may be in the form of

POGIL (Process-Oriented Guided Inquiry Learning) activities. POGIL was originally conceived in 1994, in an effort to find a better method to teach chemistry than simply lecture-based instruction [7]. Since then, POGILs have been developed across many different disciplines, although their focus is primarily STEM subjects [8]. POGIL activities are designed to be student-centered, group activities that allow participants to construct knowledge about a specific topic. For example, in a statistics course, students may receive a dataset (or a series of them) and be asked leading questions to allow them to make a connection to the objectives that have been set for the lesson. POGILs are usually done in a group of three to five students, to allow collaboration without group size becoming too unwieldy.

Similar to the Moore Method, POGILs are situated in the same theoretical framework of constructivism. Constructivism is the idea that learners of all kinds create their own understandings from within themselves, the stimuli they are exposed to, and the reflections they have on these stimuli [9]. From an epistemological standpoint, the Moore Method would likely be situated with radical constructivism, such as those views pioneered by Ernst Von Glasersfeld, who posited that everybody perceives and learns everything in a solitary fashion, and that these perceptions are unique [10]. A POGIL, however, is much more reliant on the idea that the group is more than the sum of its parts. Collaboration is key, and the participants must use the collective sum of their knowledge and abilities to learn the concepts presented to them.

III. Research Design

This work is in its beginning stages at this point; however, a great deal of care and thought has been made as to the design of this experiment. The participants for this study will be recruited from many concurrent sections of an introductory statistics course for science and engineering students at a large competitive school in the southern United States. The sections of this course are usually large, with approximately 100 students in each section. Sections are taught by three or four instructors, and participants will be recruited from all instructors' sections. The course is a service-level course and the curriculum, assignments, labs, and examinations are standard for all instructors of the course.

Participants will indicate their interest by signing up with their instructor, and they will be randomly selected from each class. An attempt will be made to keep the number of participants relatively balanced from each instructor. After all the participants have been determined, half of them will be placed into a control group, and half of them will be placed into the treatment (POGIL) group. The group that is selected for the POGIL activities will be divided into groups of four. We will be using three POGIL activities throughout the semester. The topics on which we will use POGILs are linear regression, one-sample t-tests, and ANOVA (analysis of variance). The control group will only be present in the lecture class, whereas the treatment group will complete the POGIL activity before a lecture on that material as well as participate in the class lecture. All of the POGIL activities will be audio-recorded.

At the end of the semester, we will look at individual items on examinations that were key concepts that were expected to be bolstered by participation in the POGIL as well as overall exam and course grades. We will then complete a series of quantitative analyses (likely independent samples t-tests and generalized linear models) to determine if there is a significant difference between the treatment group and the control group. Overall, we would like to know if the POGIL activities helped students on several levels. Most simply, we would like to know if the POGILs helped students perform better than the control group on test items directly related to the activities in which they participated. Secondly, we'd like to see if the POGIL activities translated into better overall course performance as well. We are likely to also perform additional exploratory data analyses to see if other interesting phenomena occur in the data we collect. We intend to run the study for at least one semester, and we may extend the study to two semesters if we have an insufficient sample size due to attrition or interest.

Additionally, in another phase of research, we intend to use the recorded POGIL sessions to inform us on the results of the quantitative analyses. That is, we believe there will be a wealth of data contained in the actual sessions that may provide us with reasons for the results we obtained from the quantitative study. These qualitative analyses may provide refinements for future studies or provide sufficient information for research in an of themselves.

IV. Discussion

We believe this research has significance because of the need to better serve students who are studying statistics, perhaps for the first time. Since statistics and the data sciences are ever growing and changing subjects due to their infancy, students can have significant difficulty navigating the range of complex and diverse material they may encounter, even in an introductory course.

We also believe that POGIL provides an ideal method for experiential growth on the part of the student. By providing activities that scaffold learning but still allow the student to work with actual data, they acquire the skills needed to be an effective consumer of statistics, which we believe should be required for any postsecondary student in today's society due to the fact that we are inundated by data each and every day in our world.

Working within the framework of a POGIL also allows students to directly address many of the common misconceptions that occur in study of statistics. The literature shows that students struggle with specific issues, like understanding variability, confidence intervals, and p-values [11]–[13]. Even skilled lecturers may have difficulty conveying these topics to students, and POGIL may provide students with the experience working with "real" data necessary to understand and overcome the complexities presented by statistical inference and modern data science.

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