Can Building an Electric Bicycle Build an Engineering Identity?

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***Abstract*— This *work in progress research to practice* paper contains a report on the effects of a STEM PBL activity, designing and building an electric bicycle, on a diverse and underrepresented group of eighth grade students. The traditional methods for engaging students in science, engineering, and mathematics activities have proven insufficient for fostering equitable engagement among students from underrepresented populations. Therefore, there is a critical need for innovative approaches that foster equity, diversity, and inclusion in engineering fields that may increase the number of students from underrepresented populations in the engineering pipeline. Based on this need, the design and scope of this study is grounded in the following question: What effects does the STEM PBL activity of building an electric bicycle have on building an engineering identity among underrepresented students? Students participating in this study will be selected at random from 8th grade students to engage in a one-day workshop led by STEM professionals where they will convert a traditional bicycle into an electric bicycle using engineering design process. The implications of this study include the infusion of innovative strategies in STEM curriculum and pedagogy that encourage greater participation of students from diverse and underrepresented populations in STEM fields.**

Keywords—Project Based Learning, Situated Learning, Engineering Identity Development, Engineering Design Process, Engineering Pipeline, Electric Bicycle, Equity, STEM Education

I. Introduction

The academic pathways in K-12 and higher education along with the field of academic and professional engineering lack diversity in the U.S.A [1], [2]. The number of students from diverse and underrepresented population groups participating in K-12 advanced academic courses required for success in engineering fields (e.g., calculus, physics) is proportionally very low when compared to that of their White and Asian counterparts [3]. The same can be said for the students pursuing academic pathways in higher education that lead to post-secondary degrees and professional licensure in engineering fields [4]. For students from every demographic, lack of participation in engineering-related courses and pathways can be attributed, among other factors, to students' perception of engineering as being an extremely difficult line of study, their lack of exposure to engineering related information and to professionals in engineering fields, and a lack of awareness of their own engineering identity [5]. These factors influencing participation are amplified even more for students from diverse and underrepresented populations due to the lack of exposure to quality STEM education in the K-12 education system. Despite the efforts made at the local and national level to address this disparity and to make access to engineering education pathways in K-12 and higher education equitable for all students, the results are not yet promising [6].

There is a need for non-traditional and innovative approaches at academic institutions to encourage the participation of diverse and underrepresented student populations in engineering coursework, which leads to them becoming a member of the professional community of engineers. This targeted effort must be aimed at K-12 academic institutions as they are the primary drivers of factors that shape students' personal and professional identities. Students' experiences in K-12 institutions shape their perceptions about the professional world and the career options available in the world around them. Depending on the extent and quality of exposure to this professional world and its inner workings, students may form opinions about professions that are incomplete or contain misconceptions.

Engineering professions are prone to having misconceptions attached to them. The principal one being that engineering is extremely difficult and boring and that becoming a professional engineer is next to impossible [6]. Employing project-based learning (PBL) activities with an emphasis on situated learning that incorporate the engineering design process, and the field of engineering in general, is an innovative solution to this problem of exposure and may help to mitigate the amount of misconceptions attached to the field of engineering.

Activities based in the theoretical framework of PBL and situated learning can afford students experiences that inform and expand their conceptions of what engineers do and how they do it. These types of activities can provide students opportunities to authentically participate within a community of learners, while situating the learning within their own personal experiences. When students are allowed to relate their academic activities with their personal experiences, the

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learning outcomes are magnified and knowledge is acquired at a deeper more personal level [7].

Students' personal beliefs about who they are dictate the profession they choose. Students who are aware of their engineering identity are more likely to pursue engineering as a profession [8]. Students' awareness of their engineering identity influences their choice of academic pathways in K-12 and higher education coursework, which directly contributes to their successful pursuit of career pathways in engineering. Exposing students from diverse and underrepresented groups to non-traditional and innovative activities that help them to discover their own engineering identity may possibly be the panacea needed to increase the participation of these students in engineering fields.

II. Purpose and Research Question

The purpose of this study is to measure the effects of a STEM PBL activity, designing and building an electric bicycle, on a diverse and underrepresented group of eighth grade students. The study will address the following research question:

1. Can a STEM PBL activity build an engineering identity in students from underrepresented populations?

III. Theoretical Framework

This study will be grounded in the frameworks of STEM project-based learning, situated learning, engineering identity development, and the engineering design process.

A. STEM Project Based Learning (STEM PBL)

STEM PBL has been defined as a "well-defined outcome with an ill-defined task" [9], as part of an interdisciplinary framework. Ill-defined tasks can be complicated in nature [10], [11], and as students engage in ill-defined tasks within a project, they explore interdisciplinary, demanding, real-life issues [12] derived from a compelling and relevant problem [13]. STEM PBLs are a model "for classroom activity that shifts away from the classroom practices of short, isolated, teacher-centered lessons and instead emphasizes learning activities that are long-term, interdisciplinary, student-centered, and integrated with real-world issues and practices" [14].

B. Situated Learning

Learning that is situated within a context is considered situated learning. A learner can be engaged in situated learning by using non-abstract activities that are socially engaging and embedded with details about particular concrete settings [15]. The basic framework of situated learning dictates that learning should require legitimate peripheral participation, activities should be centered within a concrete context, and the learner should become part of a community of practice [16]. The context for specific learning goals can be created using situations where learners participate in physical activities or by using verbal cues such as storytelling [17], [18].

C. Engineering Identity Development

Engineering identity is the awareness of a person's self as it relates to engineering. This awareness includes an individual's current relationship to engineering, his or her future aspirations in the field, and his or her self-perception of belonging in the engineering community [8]. Research shows that engineering identity has four dimensions: 1) Academic, 2) Institutional, 3) Gender, and 4) Role Models [19]. Engineering identity scales attempt to measure a person's engineering identity and have been used to measure engineering identity in women engineers, undergraduate engineering students, and elementary school students [19], [18]. Engineering identity may be impacted by factors both in and out of academic or professional institutional settings [8]; therefore, it would be beneficial to identify factors that influence a student's engineering identity.

D. Engineering Design Process

Engineering design process is defined as arriving at a well-defined outcome for an ill-defined problem using a systematic approach [21]. The engineering design process is made up of seven steps: identifying the problem and constraints, researching possible solutions, developing ideas, analyzing ideas, building, testing, and refining, and communication and reflection. STEM PBL is an invaluable tool in classrooms because it uses the engineering design process, which by its very nature necessitates and accepts multiple solutions to a problem. Projects contain constraints and teachers should assess projects by indicators [22] or rubrics based on the nature of engineering. Artifacts as the end products need to represent the concepts that students have learned while engaging in the project [23] either in writing, or verbally. Additionally, researchers [24], [25] have demonstrated that student learning is increased when students are engaged in significant activities producing real-life and practical artifacts [26]. Engaging in practical issues within PBL activities makes students' learning more relevant and expands their expertise and communication from merely an educational environment to their everyday world [27], [28], hence supporting life-long knowledge gaining [29].

IV. Methods

Through this study, researchers will attempt to measure the effects of a STEM PBL activity that incorporates the engineering design process on a diverse and underrepresented group of eighth grade students. The STEM PBL activity will consist of a four-hour long workshop in which students will be exposed to and engage in the engineering process as they learn to how design and then build an electric bicycle. To determine the effects of engaging in this study on students' engineering identity, researchers will utilize a pretest-posttest experimental study design. Quantitative data will be collected and analyzed to measure the changes in students' engineering identity.

A. Participants

Students in 8th grade from local schools will be invited to take part in the study. Flyers and brochures will be used to advertise the study. Social media outlets will also be utilized to reach a broad sample of local 8th grade students. To generate interest among students, the researchers will produce and upload promotional videos to the sponsoring program's website and contact local eighth grade teachers to request that they share the videos with their students. Google Forms or a similar web-based information gathering tool will serve as the registration portal. Basic personal and demographic information will be collected, and based on weighted criteria, 30 students will be selected and invited to take part in the four-hour long workshop. Students will be randomly divided into two groups of 15, one serving as the control group and the other acting as the experimental group. The experimental group will engage in the PBL activity while the control group will take part in a coding tutorial. Both groups will take the engineering identity survey once at the beginning of the activities and then again at the completion of the experiment.

B. *Workshop Format*

During this four to four to five-hour workshop, students in the experimental group will be introduced to the components, functions, and concepts involved in the designing and building of electric bicycles. They will conclude the workshop by converting a traditional bicycle into an electric bicycle using engineering design process. The workshop will be divided into 7 phases corresponding to the seven steps of the engineering design process [21]. During each phase, students will be introduced to a step in the engineering process within the context of building an electric bicycle.

The following sections contain a brief description of the six phases of the workshop:

1) Indentify problem and constraints: When the learning topic and activity relate to students' personal interests and experiences, students are more likely to learn and retain the information on a deeper level. At the beginning of the workshop, the student participants will be presented with the following real-life problem situation

"Adan takes a bus home from school, but, he does not like to wait at the bus stop. He lives 1.5 mile away from school. Can you help him find an alternate mode of transport to the bus?"

The statement of the problem situtation will help students put this activity within the context of their personal experiences. The statement of the problem situation will be followed by an opportunity for the students to discuss possible solutions. As the students share their proposed solutions the constraints will be introduced which will include the prefered mode of alternate transportation, available budget, and the safety requirements

2) Research: After discussing possible solutions and determining that building an electric bike while staying within the provided constraints is an ideal solution, participants will turn their attention to researching the materials needed to build an electric bike. As the participants research materials, they will encounter resources used by professional engineers. The exposure to these resoureces will allow the participants to engage in authentic practice [16]. Some of the materials students will research include motors, controllers, and batteries. As the students participate in this authentic practice, they will gain an indepth understanding of how each component works individually and its place in the over-all bicycle desgin. During this phase students will also encounter interesting facts such as batteries are measured in Ah (amm/hour) and not in miles, and components can be sourced from multiple providers. The exposure to such facts will allow participants to become a part of the community of 'engineering' practice through authentic experience [16].

TABLE I. ELECTRIC BICYCLE WORKSHOP FORMAT

	Workshop Timetable		
	Phase	***Minimum***	***Maximum***
I	Identify problem and constraints	15 minutes	20 minutes
II	Research	30 min.	35 min.
III	Ideate	30 min.	35 min.
IV	Analyze Ideas	30 min.	40 min.
V	Build	60 min.	75 min.
VI	Testing and refinement	60 min.	75 min.
VII	Communicate and reflect	15 min.	20 min.

3) Ideate: Once the students have identified possible solutions and researched the available components, they will begin to put ideas for design on the paper. During this phase they will look to combine the given restraints and the characteristics of the components available to develop an idea of what kind of electric bike is possible. The lesson learned during the last previous two phases of the workshop will guide their design ideas.

4) Analyze Ideas: The design suggestions from the previous phase will be examined for feasability during this phase. A rigorous application of the mathematics and physics concepts inivolved within the electric bicycle will be the focus of this phase. Students will also be encouraged to modify/improve their design ideas through the application of mathematics and physics concepts. For example, using mathematics to show that a smaller chainring attached to the motor's gearbox provides more torque whereas a larger chainring would provide more speed is an anticipated outcome of this phase. The goal here is to provide room for students to become an authentic member of the community of practice.

5) Build: This is undoubtedly the most anticipated part of the workshop because students finally build the electric bicycle. Students will learn as real engineers do that an error-free build is often not possible. As the students engage is the process of building the bike they will encounter multiple problems. Some natural and some introduced by the researchers. This experience will inform them about how engineers work on a day-to-day basis. Also, experiencing failures and successes during this phase will help them attain a more positive feeling towards the profession of engineering.

6) Testing and Refinement: This phase of the workshop will focus on testing the bike, finding the flaws that only become aparent during testing, and finding ways of improving the electric bicycle. Students will be encouraged to collect data during the testing process using tables, graphs, photos, videos, and verbal descriptions. Testing conditions will mimic real driving conditions as much as possible but controls will be put in place to ensure the safety of the students. Students will see that one test is not enough to collect reliable data, hence multiple riders will ride the electric bike and multiple instances of data will be collected. The data will be analyzed for refinement.

7) Communicate and Reflect: It is crucial that students are able to verbalize what they have learned during each phase of the design process. The need for communication is even greater in this final step of the engineering design process because the effectiveness of communication will determine the fate of the product being developed and tested. The need for concise communication is amplified even more because today's engineers do not work in isolation but as part of communities of engineers. Students will be encouraged to describe their evaluation of the product along with their perceptions of the results of testing and refinements.

C. Materials

An important aspect of the STEM PBL electric bicycle build activity is students' exposure to the engineering design and materials used by real engineers. During the research, ideate, analysis, and build phases of the workshop, students will encounter multiple opportunities to search for materials necessary for the build. They will assess the feasibility of the materials based on the problem statement and the restraints. For the sake of providing students participants with a meaningful STEM PBL, experienced researchers have identified the components necessary for a successful build. These components will be acquired beforehand and student participants will be introduced to components before the build phase of the workshop.

D. Survey Instrument

Researchers hope to measure the effects of STEM PBL activity, designing and building an electric bicycle on students' engineering identity. These effects will be measured using the "Affect Towards Engineering Professional Practice" survey [20]. This survey contains 34 items and measures students affect towards six constructs relating to engineering. The instrument was developed using psychometrics provided by the developers [20]. They obtained face/content validly through a two-tier process. First, they used a set of engineering and professional identity experts to examine the items and to either accept the item as is or to suggest edits. In step two, they administered the items to a sample and then performed an exploratory factor analysis to determine if the items loaded (accounted for a sufficient amount of variance) to fit their theoretical model underlying the item development. The Cronbach's alpha internal consistency reliability ranged from .74 to .88. Cronbach's alpha will be reported for the data from a when that data are available.

E. Data Collection and Analysis

Data will be collected just prior to the onset of the activity and immediately following its completion. Data will be coded and STATA 15 will be used for all data analyses. To add to the knowledge base, a structural equation model will be used to assess construct validity. The instrument uses a Likert-based scale that will be treated as continuous just as the original instrument designers did in their work. Effect sizes and confidence intervals will be calculated to assess changes in identity. We expect that students in the coding (control) group will not experience a change in their engineering identity. We believe that students engaged in the electric bicycle design and build activity will experience a shift in engineering identity. The 95% confidence interval will be interpreted according to Cumming and Finch [30]. Effect sizes will be computed and the practical improvement will be used as a benchmark for interpreting the importance of the effect of the activity on learning.

V. Anticipated Results

The researchers anticipate that the STEM PBL activity, designing and building an electric bicycle will have positive engineering identity building effects on the diverse and underrepresented 8th grade participants. Engineering design activities have been shown to provide students with learning opportunities which are situated in real-life contexts, allowing increased engagement and opportunities for authentic practice [19]. The researchers anticipate that the STEM PBL activity employed in this activity will also allow students to engage in authentic practice while impacting their engineering identity. This effect will be measured using the "Affect Towards Engineering Professional Practice" survey [20].

VI. Conclusion

Current research shows that there is a need for innovative approaches in STEM education in K-12 and post-secondary education in the U.S. The traditional methods of STEM teaching and learning have not had an impact in lessening the achievement disparity experienced by students from diverse and underrepresented population groups. Non-traditional teaching methods that provide equitable opportunities to every student must be sought and employed to ensure just participation in STEM academic and professional fields by students from diverse and underrepresented populations in the United States of America.

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