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Use of Citizen Science to Improve Student Experience in Engineering Design, Manufacturing and Sustainability Education

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Abstract

This study used the unrealized potential of citizen science as an innovative educational tool with the aim of enhancing research and learning experience of students in several engineering design and manufacturing courses with a particular focus on sustainability-related topics. Citizen science has been employed as a data collection and educational tool in two engineering courses at the University at Buffalo in which students were tasked with reporting examples of good and bad designs they observe in their everyday life. The results revealed the significant potential of citizen scientists to report innovative and informative design and manufacturing ideas.

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Keywords: Citizen Science; Engineering Education; Design and Manufacturing

1. Introduction

Engineering design and manufacturing discipline offers an inclusive framework for solving a wide range of social, economic and environmental problems. It offers tools and techniques for analyzing real-world problems. It also provides an analytical framework to identify practical solutions to those problems and establishes assessment methods to explore the impacts of alternative solutions offered by engineers and practitioners. However, the long-term ability of the design and manufacturing field to provide robust solutions depends on the timely and effective training

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of future generations of engineering designers and manufacturers.

The current study offers two advances in state-of-art educational Techniques. First, this study introduces the capabilities of citizen science as an innovative educational tool through integrating the citizen science approach into several engineering design and manufacturing courses. While citizen science has been often used to report the data related to biological species, in this study for the first time the concept of citizen volunteerism has been used to collect data about students insights about sustainability and social problems and the way design and manufacturing decisions impose such challenges. Second, the study discusses how a cyberinfrastructure framework can be developed to provide effective collection and use of data collected from citizen science projects in educational practices. In addition, crowdsourcing through citizen science helps researchers collect big datasets needed for evaluating the impact of interventions suggested by designers and manufacturers for solving sustainability and healthcare problems.

To the best of our knowledge, this is the first study introducing citizen science as an effective data collection tool for gathering data needed during the design process and highlighting the role of citizen science for improving research experience of students in engineering design and manufacturing education.

2. Background

2.1. The Critical Role of Engineering Design and Manufacturing

Although design and manufacturing has a significant role in solving practical problems and is a should-have skill for engineers, it is quite a new field of engineering. Specifically, the design process was often considered as an art rather than a science [4]. A look at the design community reveals that even engineering design research is a young field with the first Design Theory and Methodology (DTM) Conference held in 1989 [1].

Designers similar to engineers should develop at least four main broad skills. They should be able to (1) correctly diagnose problems, (2) generate and apply appropriate solution alternatives, (3) assess the effectiveness of solutions, and finally (4) accurately interpret, document and communicate the results with a wide range of clients and stakeholders.

Training the next generation of engineers is strongly influenced by the types of scientific methods that they are exposed to in the classroom settings and the type of actions individual educators take. Therefore, engineering design and manufacturing instructors should adopt better teaching practices to ensure students receive sufficient training on the skills that they will need in real-world practices. An analysis of 40 syllabi of resources systems analysis courses revealed that instructors mainly teach courses using lectures, homework assignments, exams and class projects with a very limited use of case studies, field trips and other teaching tools [2].

A question then arises of how to well align educational efforts with the actions designers undertake professionally after their graduation. To enhance engineering design education and sufficiently integrate it with real-world practice, we aim to study the impact of employing the novel and largely unexplored technique of citizen science as a teaching practice that can be adopted by educators.

2.2. Citizen Science

Citizen science is an emerging practice that has been employed in conservation biology, bio-diversity research, and natural resources science [3]. It refers to the public participation in scientific research through the collection and the reporting of data. Applications of citizen science vary from informing climate change impacts to mapping invasive species [4]. Theobald et al. reviewed 388 bio-diversity related projects and reported strong evidence of the potential of citizen science practices in collecting data for biodiversity research [5].

Although citizen science has been used for research purposes and also in several K12 education, the potential of this technique has not been used in educational setting sufficiently. Citizen science projects can enrich understanding of practical sustainability and healthcare challenges by offering students opportunities to gain early experiences that may be otherwise too difficult, costly or impractical to repeat after their graduation. Therefore there is a need for unlocking the educational benefits of citizen science [6], particularly in undergraduate education practices.

According to McDonald [7], integrating citizen science into classroom training provides several opportunities for students including, getting a sense of community and place, recognition of their selfimportance, feeling more comfortable about research, developing thinking skills, and finally exposing to the applications of the scientific methods.

Particularly, citizen science seems to have a high potential for improving science, technology, engineering, and math (STEM) curricula. Factors that influence talented students to select STEM majors in college include belief in their ability to achieve STEM, their math achievement [8] as well as the quality of academic experiences such as hands-on nature, and adequacy of preparation for future careers [9].

2.3. Active Learning

Studies report that active learning versus traditional lecturing increases students' performance in undergraduate STEM courses [10]. Although the impact of experiential education including internships, co-ops, laboratory, and project-based coursework has already been emphasized in the undergraduate STEM disciplines [11][12][13], those techniques are often costly, difficult to reproduce in reality, and are not equally available to all students. Further, students decisions to leave STEM discipline have been attributed to a variety of factors such as loss of interest in the curriculum, students' beliefs about their competence for the STEM majors [14], program cost, and the lack of knowledge about science [15]. Yet, the loss of interest is the most common reason reported by students [16]. Therefore, it seems that supporting faculty to transform their teaching techniques with incorporating citizen science as a hands-on practice not only may have the potential to improve students' performance in STEM courses but also may increase their interests in STEM majors.

Students interested in citizen science projects will be more likely to spend more time on their coursework that they would for paper homework. Implementing citizen science in design and manufacturing education can also expose students to design and sustainability projects that are fun and engaging, which could increase their interest in STEM research.

In addition, implementing citizen science projects will require the use of technology, specifically data collection, and analysis apps, so with a considerable interest in technology, it is more likely that citizen science projects may increase professional skills and the learning experience of students. Further, in contrast to lecture-driven classes, citizen science classes are observation-driven, which allows students to observe the problem and apply what they have learned within a practical context. Moreover, citizen science could also allow instructors to escape from the constraints imposed by lecture-driven classes and bring more real-life applications of lecture materials into classrooms. Finally, citizen science projects include opportunities for socialization, through the cross-institutional teams, so students involved in citizen science projects communicate with their team members which provides them the opportunity for enhancing their social skills.

The objective of the current study is to introduce the concept of citizen science in design and manufacturing education with the ultimate purpose of testing whether citizen science permits constructive, situated and experiential learning.

3. Integration of Citizen Science into Engineering Courses

In this section, we describe how we have integrated the citizen science tool into several engineering design and manufacturing courses. We had three main goals. First, we aimed to effectively include the social and sustainability topics into engineering design education. Second, we have used citizen science as both an evaluation tool and a data collection mechanism that guides engineering students in enhancing their research experiences, and finally, we aimed to study the role of crowdsourcing platforms and citizen science projects in improving students learning experiences. Our ultimate purpose is to test the hypothesis that the involvement in citizen science projects is an effective tool for improving learning experiences of students within the design and manufacturing context.

In addition to the above-mentioned objectives, the goal is to get students familiar with citizen science as an effective data collection tool in addition to survey studies, focus group, and historical datasets that are often used during the conceptual design stage to collect data on stated consumer needs and preferences. Therefore, introducing the concept of citizen science not only may improve students learning experience but also educate them about a new data collection technique to use during the conceptual design and market analysis of product design alternatives.

3.1. Sustainability-related Courses

Our main focus was on sustainability and healthcare related topics. Sustainability and healthcare problems are often fundamentally multidisciplinary, requiring significant investments in opportunities for education of US workforce that has the skills and experience necessary to solve multi-dimensional problems. Sustainable solutions require designing complex sociotechnical systems. To best design such systems, engineers will need a holistic view of the work, and a clear understanding of the role of their work in meeting society's needs.

Although many programs, centers, and activities developed over the past several decades with the aim of actively involving undergraduates directly in the iterative research processes, often the opportunity is limited to those students who show some interests or are looking for the research opportunities. Therefore, a majority of students are not exposed to any research experience even throughout the whole period of their studies.

Citizen science projects help students experience and understand the procedure of research, rather than delivering of specific research content. They allow students to learn both research content and the way scientific questions are asked and addressed by the research community [17].

We have included citizen science projects into two engineering design and sustainability-relevant courses at the University at Buffalo, namely (1) design processes and methods, and (2) sustainable manufacturing courses.

We have selected the target courses using three criteria: (1) courses that cover engineering innovation and design topics, (2) courses that cover sustainability-related subjects (e.g. social, economic, and environmental context), and (3) courses that address system design as well as product design. In addition, since the above-mentioned courses were taught by the authors, it provided more flexibility in defining relevant assignments and guiding students during experiencing citizen science projects. The topics of citizen science projects can be tailored according to the requirement and teaching objectives of each course. Overall, any data-driven course subjects might be a good fit for implementing citizen science projects.

Employing the above-mentioned criteria, the following courses have been targeted for the citizen science projects:

Design Processes and Methods: This course discusses the fundamental concepts and domain-independent topics of design processes including decision making, conceptual design, design concepts generation, cost evaluation, customer needs analysis, ethics, decision maker's irrationalities and cognitive biases, and intellectual property issues. The total enrollment for this course is 300 students and is offered in three separate sections. We have incorporated citizen science into one section of this course (e.g. total of 96 students).

Sustainable Manufacturing: The course is designed for undergraduate students who are interested in furthering their knowledge in green engineering techniques. The approaches presented in this class are from the levels of manufacturing, machine, and systems, as well as the overall product lifecycle and supply chain perspective. It discusses the principles of green manufacturing including lower usage of materials and energy, substitution renewable input materials with non-renewable, reduce unwanted outputs/waste, close the loop (convert outputs to inputs through recycling, recovery, reuse), re-engineering the structure of the systems through revised supply chain structure and changing the ownership concept in the system (introduction of product service systems). The average enrollment for this course is 70 students.

3.2. Citizen Science Project: Report Examples of Good and Bad Designs

To show the potential of using citizen science for educational purposes, we have invited about 160 students as citizen scientists from the above-mentioned course to participate in a design-report assignment. In practical research-based citizen science projects, the number of volunteers is often more than a couple hundred participants. However, in this study, citizen science is used as an educational tool.

The purpose of data collection was to report instances of 'bad design' students observe in everyday life, and particularly on the University at Buffalo (UB) campuses. Students were tasked with taking a selfie with a bad and good design found on UB campuses or elsewhere and reporting a description of the design and location along with several other pictures clarifying the geometry and size of the problem. Various samples of efficient and inefficient designs were reported ranging from too-high tables to the waste of natural lights in office spaces. This experience reveals the significant potential of citizen scientists to report innovative and informative ideas. What makes the citizen science assignment different than regular homework assignments is its nature of field work, observations, and reporting the results of observations. Through this assignment, students experience the application of citizen science as a data collection tool.

In practice, often public and non-scientific volunteers help with citizen science projects. Therefore, it is important that volunteers have basic observation skills, and receive sufficient training before going to the field sampling and help scientists with collecting accurate data. In this class assignment, students are not considered as amateurs since they already knew minimum concepts about product design principles. Therefore, less training was required for this group. In addition, the purpose of data collection was mainly education and not conducting research. Therefore, the quality of data collected by students was not our primary concern. In addition, the nature of this specific assignment was very open-ended in which students were tasked to report any examples of unsuccessful design of their choice, therefore minimum guidelines and instructions were needed compared to biology and natural resources science projects.

3.3. Examples of Designs Reported by Students

This section provides some analyses on the design examples reported by students. The focus of our analysis was on designs that have been classified as 'bad' design. Total 112 pictures of different designs reported by students have been selected for analysis. Various designs were reported such as the sharp edge of laptop cases, overheating problems in electronic devices, improper size, and geometry of various products, improperly scheduled elevators, poorly positioned components, motion sensor faucets. Figure 1 shows a few samples of pictures submitted by students.

Fig. 1. Sample of design pictures submitted by students

We have categorized the designs into four main categories of (1) electronic devices, (2) architectural designs, (3) furniture, and (4) others. Table 1 shows the number of designs under each category. It appears that electronic devices with 40% were among the most reported designs by students.

Table 1. Types of designs reported by citizen scientists

Design category	No. of design	Percentage
Electronic devices	45	40%
Architecture	15	13%
Furniture	10	9%
Other	42	38%

Analyzing the descriptions of designs revealed that students have reported a design as a bad design mainly due to one of the following reasons: (1) improper size and geometry, (2) safety and health-related issues, (3) confusing design, and (4) missing features. If students have commented on the improper functionalities of a design, we have categorized that design under *missing features* category. Table 2 shows the classifications of reasons behind designs reported as unsuccessful designs.

Table 2. Reasons behind unsuccessful designs

Design category	Number	Percentage
Improper geometry and size	43	39%
Safety and health issues	18	17%
Confusing design	14	13%
Missing features/not working as intended	34	31%

Figure 2 shows several examples of designs reported having safety and health issues.

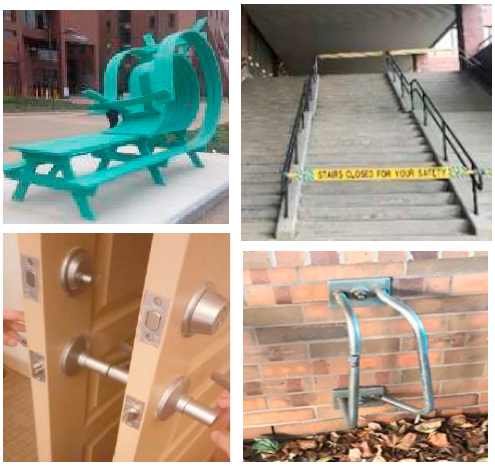

Fig. 2. Sample of designs with safety issues

It should be noted that the purpose of this study is not to analyze the design and manufacturing data reported by citizen scientists, but to show the capabilities of citizen science in involving undergraduate students in research projects and enhancing their learning experiences in design and manufacturing courses.

One objective of the project was to introduce students to new data collection tools available to them beyond just survey, focus group, and historical data. The first part of the course is mainly focused on teaching data collection tools that can help designers collect proper information about consumer needs and the market under study. Students get familiar with the limitations of existing qualitative data collection tools such as survey and focus groups since they are often helpful in collecting stated behaviors of consumers rather than actual behaviors. Then, citizen science is introduced as a new data collection tool that can help them gather required information in their predefined context. Students further have collected data for the particular assignment to experience the use of citizen science for both identifying and reporting design.

The students have been mainly involved in data collection activities. However, they have been asked to not only provide a description of a design, and several pictures of the design (including a selfie and several non-selfie pictures) but also specify the reasons why this is not a good design. They have been asked to select one of the seven available reasons including 1) improper geometry and size, 2) Missing features, 3) Extra features, 4) Safety and health issues, 5) Confusing design, 6) Low-performance design, and 7) Other.

While we have not measured the exact impact of the citizen science project on students learning outcomes, we have received a considerable number of positive comments on the mid-term course evaluations, where more than 60% of students commented that they found the citizen science assignments useful in learning the way to identify proper design and sustainability-related problems.

In addition to mid-term course evaluation, the end-of-semester course evaluation also shows students interests in projects and citizen science assignments as part of their projects. Examples of comments listed by students in the “Course element found effective” section of course evaluation are: “The course project was by far the most effective part of the course. Going through the design process through that project is very useful.”, “The project is very relevant to real life engineering experience so that is an element that I find very effective!”, and “The topics were helpful in better understanding the design process.”

In this study, the evaluation of citizen science as an educational technique was limited since this was the first year of using citizen science as part of the course. The experiment to test the effectiveness of the citizen science will be a comparison of the outcomes from the one section of the course using citizen science with the two other sections that are not using it. However, while the class size, time of day, and day of week, all were the same for all three sessions of this course since two other sessions were taught by a different instructor, we were not able to attribute the learning outcomes of the sessions to citizen science technique.

3.4. GIS-based App to Engage Students in Data Reporting

The advances in technologies enable educators to design websites and educational apps where participants will be able to learn about the citizen science project, register as a volunteer, read the instructions and record their observations related to the defined projects.

For example, for the educational purposes as part of this study, we could develop a smartphone GIS-based reporting application that will be freely available to the students where participants will be able to report examples of good and bad design on the campus. Currently, free app templates enabled educators to easily draft such apps. For example, we would configure the Quick Report app template provided by AppStudio for ArcGIS to create a native app for students' engagement that allows users to capture their observations and then submit them to an online server (Figure 3). Educators can customize the app based on the requirements of their projects: for example, 1) self-report of products owned by users and, 2) other observations made by users. The apps can be distributed on Google Play (Android), App Store, Mac App Store, Windows Store, and Ubuntu Apps Directory to make it available to other institutions and users.

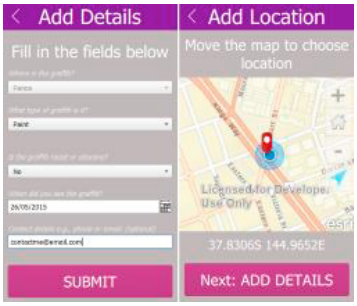

Fig. 3. Sample of app created by Quick Report, AppStudio, ArcGIS [18]

4. Closure

The purpose of this study was to use citizen science with the aim of enhancing students learning experiences in engineering design and sustainable manufacturing education. The applications of citizen science in the environmental management field are at their early stage, particularly, the number of educational citizen science projects is very limited. No citizen science projects have been developed to educate engineering design students on the impact of design and manufacturing. We have incorporated this citizen-scientist style of learning into two engineering design and manufacturing courses to educate students on environmental management concepts.

The current study has engaged around 160 students in sustainability-related courses. The project spans several engineering courses with complementary expertise in sustainable design, social science, and complex systems modelling. Although the focus of the current study was on design and sustainability courses, design is a decision-making process that is embedded in almost all engineering disciplines, therefore the success of this study facilitates citizen science-based learning in engineering education in general. In addition, given the emerging power of social media and the increased availability of public in assisting researchers, this study is one step towards educating engineering students on the way they can use the power of public knowledge in solving engineering design and manufacturing problems.

Future work includes the use of citizen science in additional engineering courses and the comparison of students' performance across different majors and various class sizes. Future implementations in educational settings also include conducting appropriate experiments using the smartphone apps discussed in Section 3.4.

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