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Teaching Wind Energy to Engineering and Education Undergraduates Through Community Engagement

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Abstract Rhode Island's adoption of the Next Generation Science Standards in 2013 [1] established a pressing need to provide elementary schools with support for integrating engineering in our local district's classrooms. Wind energy was identified as an appropriate instructional topic, both for its relevance to Rhode Island [2], and for its strength as a tool for studying the engineering design process. Education and engineering undergraduates collaborated to educate local fourth graders about engineering design and wind energy. While supporting the need for engineering education in the community, this project also deepened learning for both education and engineering students at Roger Williams University.

Keywords: *Experiential Learning, Community Engagement, Engineering Design, Wind Energy Education*

1. Introduction

In 2013, Rhode Island adopted the Next Generation Science Standards (NGSS) prompting an effort to align curriculum and instruction with the new vision reflected in the NGSS [3]. The Bristol Warren Regional School District, where our university is located, was one of eight Rhode Island school districts that were involved in a collaborative project, the *Building a Strong Foundation* science initiative, that "led to the publication of a K-12 RI Model Science Curriculum aligned to the Next Generation Science Standards" [4]. One of the challenges the district faced while implementing the model curriculum was the elementary school teachers' lack of familiarity with the engineering practices and core ideas that are explicitly included in the NGSS. Thus, the district had the pressing need to provide the elementary school teachers with the support for integrating science and engineering in their classrooms.

The needs of the local school district prompted the creation of an interdisciplinary community engagement project, linking engineering and education courses at our liberal arts university. This work included joint efforts from an upper-level engineering elective course, Sustainable Energy Systems, and a sophomore-level education course, Teaching Inquiry Science in the Elementary School. The engineering students provided technical expertise about energy, the wind resource, and wind turbines. Meanwhile, education students complemented engineering students' content proficiency with their emerging expertise in planning grade-specific and NGSS-aligned science lessons.

The district identified the fourth-grade teachers and students for participation in the collaborative project because the instructional topic of wind energy is well-aligned with the NGSS performance expectations and the district science curriculum's units of study for Grade 4.

2. Community Engaged Learning

Service learning, or community engaged learning, is described by Hatcher and Bringle as a "credit-bearing educational experience in which students participate in an organized service activity that meets identified community needs...to gain further understanding of the course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility" [5]. There are many documented benefits of community engaged learning projects across numerous academic disciplines, including growth in critical thinking, interpersonal, leadership, and communication skills. Furthermore, there is evidence that these projects increase recruitment, retention, and graduation rates among student participants, particularly for women and minorities [6].



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Community engaged learning is a natural fit for engineering courses where theoretical concepts taught in the classroom can be applied in real-world settings. Furthermore, this pedagogy has demonstrated success at fulfilling Accreditation Board of Engineering and Technology (ABET) outcomes such as “an ability to communicate effectively,” “an ability to function on multidisciplinary teams,” and the training to “understand the impact of engineering solutions in a global, economic, environmental and societal context” [7].

Rhode Island Standards for Educator Preparation Standard Two: Clinical Partnerships and Practice states that “approved programs ensure that high-quality clinical practice and effective partnerships are central to preparation so that candidates develop the knowledge, skills, and professional dispositions necessary to demonstrate positive impact on PK-12 students’ learning and development” [8]. To truly actualize this educator preparation standard, education students must be involved in the partnership with school community partners throughout their educational experience. Community engaged learning provides education majors with practical opportunities to apply their pedagogical content knowledge and skills in service to others and then reflect on the impact of their interventions on students’ learning.

3. Project Planning

The community engagement project was carried out in the Spring 2019 semester. Prior to implementation, various planning and preparation activities were completed. The chronology of project planning activities is provided in Table 1, below, followed by a discussion.

Table 1: Overview of the project planning activities.

Summer 2018	
<i>June - August</i>	Project Planning and Coordination <ul style="list-style-type: none"> • Grants and gifts solicitation • Curriculum planning for ENGR 340 and EDU 342 Wind Tunnel designed and built by engineering research assistant
Fall Semester 2018	
<i>September - December</i>	Continued Project Planning and Coordination <ul style="list-style-type: none"> • Syllabus development by engineering and education faculty members • Planning meetings with the local school district (schedule development, logistics, goals) • KidWind curriculum development by education research assistant • Energy measurement and data-logging method selection and mastery completed by engineering research assistants

In the summer leading up to the project, the curriculum from the engineering and education courses needed to be coordinated and further developed. This included planning assignments and aligning schedules across the courses. The overarching goal was to not only ensure the learning outcomes of each course were met, but that they would be strengthened by this community engagement project.

Additionally, over the summer a rising senior engineering student designed and built a wind tunnel for the project. The wind tunnel would be used to measure the energy output of the wind turbines whose blades were to be designed and built by the fourth grade participants. It needed to be designed such that off-the-shelf box fans could provide the wind. Additionally, the design needed to be simple and easy to disassemble and reassemble, such that it could be stored and easily transported. Finally, the design needed to allow an audience to observe the wind turbines rotating in the presence of wind. The tunnel design was drawn using 3D CAD software and built using largely off-the-shelf products from a local hardware store.

In the Fall semester, curriculum coordination between the engineering and education courses continued, including finalizing the course syllabi. Meetings were held with the local school district to discuss science standards and curricular outcomes, schedule the project dates, and identify the professional development needs of the fourth grade teachers. An education student worked as a

research assistant to align the fourth grade NGSS performance expectations with the curriculum developed by KidWind [9], which is designed for middle and high school students. Meanwhile, engineering research assistants assessed energy measurement and logging tools in order to select a method most appropriate to our project.

4. Project Implementation

The project consisted of three main components; a day-long professional development workshop for the fourth-grade teachers, five lessons on wind energy that were planned and taught by undergraduate education and engineering students, as well as a culminating celebration event. Upon completion of the three pieces of the projects, the engineering and education students worked within their disciplines to complete final deliverables. An overview of the project chronology is provided in Table 2, below.

Table 2: Chronology of the project over the course of the semester.

Spring Semester 2019	
<i>January 31</i>	Professional Development Event for 4 th Grade Teachers at our university's campus <ul style="list-style-type: none"> • Strengthen understanding of the engineering design process vs. the scientific method • Design, build, and test wind turbine blades with the KidWind equipment
<i>February – April</i>	Five lessons designed and taught by interdisciplinary teams of education & engineering students in each of the 4 th grade classrooms <ul style="list-style-type: none"> • Topics include: energy, wind, engineering design, and blade design & testing
<i>April 12</i>	KidWind Celebration Event <ul style="list-style-type: none"> • Wind turbine testing in a wind tunnel to measure energy performance • Two hands-on engineering design activities to reinforce the design process • Presentations to a panel of experts from TPI Composites • Scavenger hunt with engineering related puzzles
<i>April 29</i>	Poster Presentations at our university's undergraduate research conference <ul style="list-style-type: none"> • Each teaching team of education and engineering students presented a poster documenting their work in a class-specific session

The project was launched in earnest in January with the first major component, a one-day professional development workshop for the eleven fourth-grade teachers in the school district, as well as the Assistant Superintendent. The goals of the workshop were threefold: 1) to train teachers about the engineering design process (as opposed to the scientific method), 2) to instill teachers' competence and confidence with model-scale wind turbines (from KidWind [9]), which would soon be used in their classrooms, and 3) to provide an opportunity for insightful discussion between RWU faculty and fourth-grade teachers, including discussion about best practices in the elementary teaching environment.

The morning of the workshop introduced fourth grade teachers to the engineering design process through a hands-on activity that challenged participants to build towers out of spaghetti and modeling clay. The activity acquainted the teachers with an engineering mindset and related vocabulary. Furthermore, the activity modeled an example of curriculum that would soon be introduced to their classrooms by our undergraduates. In the afternoon, the fourth-grade teachers interacted with the wind turbines, through designing and building wind turbine blades of their own. The blades were tested for power performance across changing variables, such as pitch, blade length, and number of blades. Additionally, the workshop outlined the wind energy curriculum that the undergraduates would bring to their fourth-grade classrooms. The workshop counted as a day of professional development for the teachers, including full support from the Superintendent and Assistant Superintendent of the local school district.

The second piece of the project began in February when our undergraduate students began teaching their first lessons in the elementary schools. Twenty-nine engineering and forty-eight education students were placed into eleven multidisciplinary teaching teams. Each team worked exclusively with

one of the eleven fourth-grade classrooms, spanning across four elementary schools, for the entirety of the project. Students collaborated throughout the Spring semester to produce a series of five lesson plans, each lasting one hour. The education students brought proficiency in planning NGSS-aligned lesson plans, which the engineering students complemented with their emerging expertise in wind energy and physical principles. Draft lesson plans were submitted to the engineering and education professors 10-days ahead of the lesson. After receiving and incorporating feedback and suggestions from the faculty, the lesson plans were shared with each team's designated fourth grade teacher for a final review before teaching.

The curriculum for the five lessons was adapted from the KidWind Program to align with our younger audience and tight timeframe [9]. In weeks one and two, lessons covered the topics of energy, wind as a resource, and wind turbines, including issues of siting and environmental impacts. Then, in week three, our undergraduates introduced the fourth graders to the engineering design process. Additionally, the fourth graders began to interact with the KidWind model turbine kits during the third lesson. Across the eleven classrooms, fourth graders were placed in 57 teams who each received a set of basic turbine building parts, including a turbine hub, generator, and dowels to attach up to twelve turbine blades. The wind turbine blades were constructed from recycled materials, such as cardboard, soda bottles, paper, etc. Finally, in weeks four and five, the fourth graders followed the iterative engineering design process to design, build, and test their wind turbine blades using box fans. Initially, fourth graders focused on the mechanical energy production of their blades by lifting weights. Then, in the final lesson, students used LEDs and multimeters to assess the electrical energy production from their blades. Upon completion of the five classroom lessons, each of the 57 teams of fourth graders had a set of finalized blade designs to bring to our campus.

Finally, the third project component occurred in mid-April, when over 230 fourth graders and their eleven teachers came to our university's campus for a day-long celebration of their accomplishments. We had initially planned for the fourth graders to compete to see whose blade designs could produce the most energy. However, the fourth grade teachers suggested this would lead to hurt feelings, and suggested the event be more celebratory in nature.

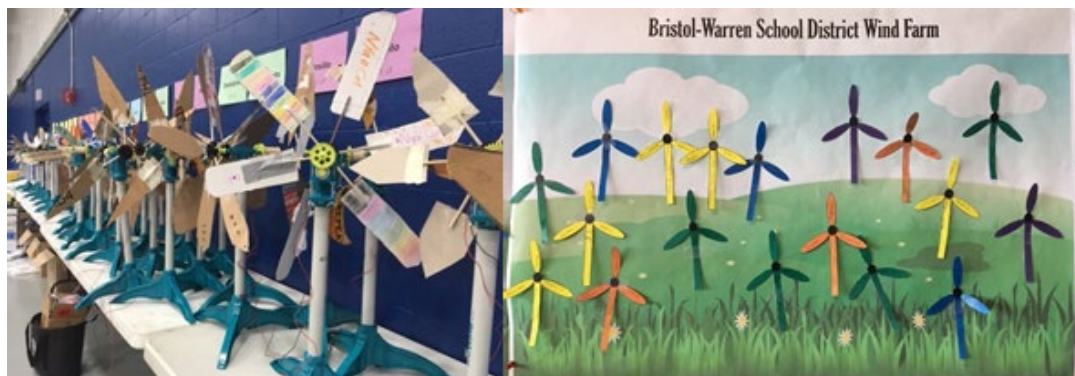


Figure 1: KidWind model turbines with blades designed, built, and tested by fourth graders (left). Part of the school district wind farm where each turbine represents a team of fourth graders who tested their turbine in the wind tunnel (right).

The day began with brief welcoming remarks, followed by a series of five round robin stations. The fourth graders were assigned to five groups that rotated through each round robin station over the course of the day. Our undergraduates served in various roles throughout the day, for example as round robin station facilitators, class chaperones, logistics managers, or as wind tunnel operators. At two of the stations, fourth graders were guided through engineering design activities that were not wind energy focused. This was done purposefully, to remind participants that the engineering design process is used widely and not just for the purpose of designing turbine blades. At one of the engineering design stations, students designed catapults with popsicle sticks, rubber bands and

pompoms, and at the other, fourth graders created bridges out of printer paper. Participants completed an engineering-themed scavenger hunt at the third station. Next, fourth graders presented their designs to a panel of experts, which was staffed by engineers from TPI Composites who generously volunteered their time. Finally, at the fifth station, all 57 turbines were tested in a wind tunnel. A projector screen displayed the energy production of each team's turbine, and after completing testing, each team added a paper wind turbine to the school district's wind farm, shown in Figure 1, below.

Each multidisciplinary teaching team presented a poster at our university's undergraduate research conference, which occurred shortly after the day-long celebration event. The poster presentations gave the students an opportunity to share their work with the wider university audience, as well as grow in their communication skills.

At the conclusion of the semester, engineering students worked with the other engineers from their teaching teams to create project portfolios documenting their KidWind community engagement project. The students were asked to document their project planning process, discuss their community partner's identified needs, reflect on their learning, suggest improvements for future years, and finally provide all lesson plans in an appendix.

After the KidWind unit instruction was concluded, education students made a final round of revisions on the five lessons based on how their teaching went, and on the comments from their faculty and the 4th grade teachers. In addition, education students further developed the differentiation strategies to meet diverse learner needs for each lesson and create a summative assessment to measure 4th grade students' proficiency level in meeting the targeted NGSS Performance Expectations at the end of the set of lessons. A copy of the finalized unit plan along with any instructional materials created for each lesson was provided to each 4th grade teacher as a curriculum resource.

5. Research Procedures and Methodology

Project assessment was carried out through pre- and post-tests across four participant populations: 4th-grade students, 4th-grade teachers, as well as education and engineering undergraduates, with metrics exploring self-efficacy as well as content knowledge. Each assessment was designed to take no longer than 20 minutes. The pre-tests were administered in late January and early February before the project began. The post-tests were completed in late April and early May, after the final celebratory event. Project outcomes are assessed by comparison of baseline data (before the project begins) against results at the conclusion of the project.

The education and engineering students completed pre- and post-tests that assessed their comfort/self-efficacy/confidence in teaching engineering, as well as their understanding of the engineering design process, energy, energy conversion, and wind energy concepts. The assessments were administered in the engineering and education classrooms, in the absence of their course instructor. This paper presents the engineering teaching self-efficacy results from the pre- and post-tests administered to the engineering and education students only. The other assessment outcomes are not included in this work and will be presented in a future paper.

The engineering teaching self-efficacy survey was adapted from the established Teaching Engineering Self-Efficacy Scale (TESS) with 41 items [10]. Satisfactory content validity of the TESS was established by a panel of professors and graduate students in engineering and education disciplines. The construct validity was demonstrated using the Exploratory Factor Analysis (EFA), which shows all 41 items had significant factor loadings onto one of six factors, indicating each item's unique contribution to one of the factors. The overall reliability of the TESS was Cronbach's $\alpha = .979$ from $N = 153$ [10]. The TESS was edited for length and a different participant population in our study (The target population for the use of the TESS is the K-12 teachers in the United States while our participants are education and engineering undergraduates). The adapted scale includes 18 six-point Likert-scale statements measuring three dimensions of engineering teaching efficacy: engineering pedagogical content knowledge self-efficacy (9 items), motivational/engagement self-efficacy (4 items), and outcome expectancy (5 items). Response categories are "strongly disagree," "moderately disagree," "disagree slightly more than agree," "agree slightly more than disagree," "moderately

agree,” and “strongly agree.” Each response category is assigned a numeric value between 1 (strongly disagree) and 6 (strongly agree), and the values are used to compute the average score for each statement.

6. Results and Discussion

Forty-three education students completed both pre- and post-tests. Comparison of their engineering teaching efficacy measured in the pre- and post-test is presented in the tables below. Education students scored higher in each statement in the post-test than in the pre-test. In fact, their average post-test score for each statement but one (“I can teach engineering as well as I do most subjects”) is 5 or higher while most of the average pre-test scores for the 18 statements are between 2 and 4.

Twenty-eight engineering students completed the pre-test and twenty-nine completed the post-test. The results of their pre- and post-tests are shown alongside the education students’ in the tables below. The scores improved across all questions between the pre- and the post-test. Most of the average pre-test scores for the engineering students were close to 4, while the average post-test scores were all 5 or greater, except for one (“I can motivate students who show low interest in learning engineering”).

Table 3: Responses from education and engineering students assessing their perceived self-efficacy in engineering pedagogical content knowledge.

<i>Engineering Pedagogical Content Knowledge Self-efficacy</i>	Education Students		Engineering Students	
	Pre-test	Post-test	Pre-test	Post-test
1 I can explain the different aspects of the engineering design process.	2.3	5.4	5.1	5.9
2 I can assess my students' engineering design products.	2.8	5.5	4.5	5.8
3 I know how to teach the engineering design process effectively.	2.2	5.4	4.0	5.5
4 I can teach engineering as well as I do most subjects.	2.1	4.4	4.3	5.5
5 I can employ engineering activities in my classroom effectively.	2.8	5.2	4.2	5.6
6 I can discuss how engineering is connected to our daily life.	3.7	5.7	4.8	5.8
7 I can create engineering activities at the appropriate level for my students.	3.3	5.4	4.1	5.3
8 I can recognize and appreciate the connections between engineering and other STEM fields.	3.4	5.1	4.6	5.6
9 I can guide my students' solution development with the engineering design process.	2.8	5.3	4.2	5.5
Dimension average	2.8	5.2	4.4	5.6

The dimension of engineering teaching efficacy that education students show the greatest improvement is “engineering pedagogical content knowledge self-efficacy,” for which the average dimension score went from 2.8 (between “moderately disagree” to “disagree slightly more than agree”) in the pre-test to 5.2 (between “moderately agree” to “strongly agree”) in the post-test. In this same category, engineering students rated themselves much higher at the start of the project, with an average pre-test score of 4.4, which rose to 5.6 in the post-test. The gap between education and engineering students’ pre-test scores is likely due to the early training the engineering students receive about the engineering design process, which was relatively new curriculum for the education students

at the start of our community engagement project. By the end of the project, the post-test scores are both above 5, indicating that regardless of their major, student participants felt capable in their knowledge of engineering pedagogical content knowledge. The results are shown in Table 3, above.

Table 4: Responses from education and engineering students assessing their ability to motivate 4th grade students in learning engineering.

		Education Students		Engineering Students	
		Pre-test	Post-test	Pre-test	Post-test
<i>Motivational Self-efficacy</i>					
10	I can motivate students who show low interest in learning engineering.	4.3	5.4	3.8	4.6
11	I can increase students' interest in learning engineering.	4.3	5.5	4.1	5.0
12	Through engineering activities, I can make students enjoy the class more.	4.3	5.6	4.2	5.3
13	I can encourage my students to interact with each other when participating in engineering activities.	4.7	5.7	4.2	5.2
Dimension average		4.4	5.5	4.1	5.0

For the “motivational self-efficacy” dimension, shown in Table 4, the trends flipped. In this dimension, education students had an average pre-test score of 4.4, which rose to 5.5 by the end of the project. The beginning score of 4.4 indicates that education majors felt confident and capable in their ability to motivate their students learning and interest in engineering. Meanwhile, engineering students started the project with a lower average pre-test score of 4.1, and ended the project with a post-test average score of 5.

Table 5: Responses from education and engineering students on their personal belief in the effect of teaching on student learning of engineering.

		Education Students		Engineering Students	
		Pre-test	Post-test	Pre-test	Post-test
<i>Outcome Expectancy</i>					
14	I am generally responsible for my students' achievements in engineering.	3.9	5.1	4.3	5.1
15	When my students do better than usual in engineering, it is often because I exerted a little extra effort.	3.8	5.0	4.2	5.0
16	My effectiveness in engineering teaching can influence the achievement of students with low motivation.	4.3	5.3	4.4	5.0
17	If I increase my effort in engineering teaching, I see significant change in students' engineering achievement.	4.3	5.4	4.5	5.4
18	I am responsible for my students' competence in engineering.	4.3	5.2	4.5	5.1
Dimension average		4.1	5.2	4.4	5.1

Finally, in the “outcome expectancy” dimension reported in Table 5, the education students' average score grew from 4.1 in the pre-test to 5.2 in the post-test. The engineering majors' average pre-test was slightly higher than the education majors', with a score of 4.4. However, by the

conclusion of the project, the engineering students' post-test average was 5.1, which fell just below the education students' average reported score.

Table 6: The average responses from education and engineering students between pre- and post-tests across all survey questions.

	Education Students		Engineering Students	
	Pre-test	Post-test	Pre-test	Post-test
Overall Average	3.6	5.3	4.3	5.3

Through community engagement, the engineering and education undergraduates deepened their learning about wind energy and the engineering design process. The results clearly show that the KidWind project helped education students develop much higher efficacy in teaching engineering, which is essential for these future teachers because "teachers' sense of efficacy (i.e., the extent of their belief that their efforts affect student learning) has been shown to be a significant indicator of effective teachers" [11] Meanwhile, engineering students grew in their ability to communicate technical content to nontechnical audiences.

7. Conclusions

A community engagement project involving interdisciplinary collaboration between engineering and education courses, in collaboration with the local school district, educated fourth graders about engineering design and wind energy. College participants worked in small teams to design and implement five lessons on wind energy in eleven local 4th grade classrooms. The project culminated with a celebration event on our university's campus in which over 230 fourth graders participated in a round robin of activities facilitated by engineering and education majors, including testing their wind turbines in a wind tunnel.

The project not only met the needs of the school district, but also enhanced undergraduate learning through hands-on, experiential engagement with the community. Assessment data demonstrates increased engineering teaching self-efficacy in engineering and education undergraduates. Among the three engineering teaching self-efficacy dimensions, both groups of students showed the greatest improvement in engineering pedagogical content knowledge self-efficacy. Education students' average dimension score increased from 2.8 in the pre-test to 5.2 in the post-test, while engineering students' average score went from 4.4 to 5.6. The findings suggest that education and engineering students not only developed an enhanced understanding of content knowledge about the engineering design process, pedagogical knowledge, learners, and learning environments but also learned how to integrate the different categories of knowledge through their participation in the project.

As Rhode Island experiences continued growth in offshore wind energy, this work contributes to the preparation of the future workforce, both at the fourth-grade and collegiate level. The success of the pilot year ensured continued collaboration between our university and the local school district for future years.

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