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A Comparative Study of Educator Backgrounds and Their Effect on Student Understanding of the Engineering Design Process and Engineering Careers, Utilizing an Underwater Robotics Program (RTP)

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Abstract

Numerous studies have demonstrated that educators having degrees in their subject areas significantly enhances student achievement, particularly in secondary mathematics and science (Chaney, 1995; Goe, 2007; Rowan, Chiang, & Miller, 1997; Wenglinsky, 2000). Yet, science teachers in states that adopt the Next Generation Science Standards are facilitating classroom engineering activities despite the fact that few have backgrounds in engineering. This quantitative study analyzed ex-post facto data of 81 educators and 2,455 students who participated in WaterBotics, an innovative underwater robotics program for middle and high school students. This study investigated if educators having backgrounds in engineering (i.e., undergraduate and graduate degrees in engineering) positively affected student learning on two engineering outcomes:

1) the engineering design process, and
2) understanding of careers in engineering (who engineers are and what engineers do).

The results indicated that educators having backgrounds in engineering did not significantly affect student understanding of the engineering design process or careers in engineering when compared to educators having backgrounds in science, mathematics, technology education, or other disciplines. There were, however, statistically significant differences between the groups of educators. Students of educators with backgrounds in technology education had the highest mean score on assessments pertaining to the engineering design process while students of educators with disciplines outside of STEM had the highest mean scores on instruments that assess for student understanding of careers in engineering. This might be due to the fact that educators who lack degrees in engineering but who teach engineering do a better job of "sticking to the script" of engineering curricula.

Introduction

Darling-Hammond determined that one of the most important factors that influences student learning is "what teachers know" (Darling-Hammond, 2000). Furthermore, numerous foundational studies have demonstrated that teachers with majors in their subjects have significantly positive effects on student achievement, particularly in secondary mathematics and science (Chaney, 1995; Rowan, Chiang, & Miller, 1997; Wenglinsky, 2000). Few researchers, however, have examined whether formal training in engineering actually does improve the teaching of engineering in K-12 classrooms or whether formal training in subjects such as mathematics would better suit the K-12 teaching of engineering. As more states adopt the Next Generation Science Standards, more science teachers are tasked with teaching engineering in the classroom despite few having backgrounds in engineering. Therefore, this study investigated whether formal training in engineering and/or other subjects such as mathematics improved student learning of the engineering design process and enhanced student understanding of careers in engineering (i.e., of who engineers are and what they do) of students who participated in the

WaterBotics program. This quantitative study analyzed and interpreted ex-post facto data of 81 educators and 2,455 who participated in WaterBotics.

WaterBotics is an underwater robotics curriculum in which middle and high school students learn about science and engineering concepts and careers by working in groups to build submersible robots made of LEGO® components. Using LEGO® Mindstorms® NXT software, students program controllers that enable their remotely-operated underwater robots to perform a series of increasingly complex "missions." The curriculum takes approximately 20 to 26 hours to implement. WaterBotics was developed by the Center for Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology.

Of the educators who participated in WaterBotics, 16% had backgrounds in engineering. Therefore, data was analyzed to determine if there would be a relationship between educator backgrounds, specifically teachers who had backgrounds in engineering, and student engineering outcomes in the WaterBotics program.

To procure these data, CIESE faculty and staff conducted professional development programs for the WaterBotics curriculum in conjunction with its grant partners, the League for Innovation in the Community Colleges (League) and the National Girls Collaborative Project (NGCP). The League selected community colleges that "turn keyed" the WaterBotics curriculum to formal "hub sites" that included middle and high school classroom educators while the NGCP partners "turn keyed" the curriculum to informal (i.e., after school program and summer camp) girl-serving "hub sites" (47.6% of the student participants in this study were female). For each hub site, CIESE staff facilitated a one-week, hands-on training session of the WaterBotics underwater robotics curriculum delivered to hub site educators. Follow-up support from CIESE included scheduled quarterly conference calls as well as web meetings for hub site educators. See Figure 1 for the training model.

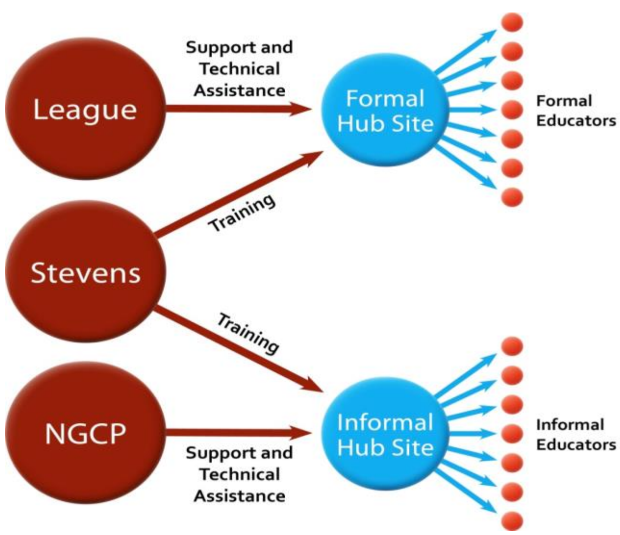


Figure 1. Train the Trainer Model for the WaterBotics Program. Source: www.waterbotics.org

All WaterBotics educators were provided with extensive written and online curricular materials that included embedded assessments and resources for teaching the engineering design process and careers in engineering. Videos pertaining to engineering careers were embedded into the curriculum for WaterBotics educators to use as teaching tools. The curriculum also included descriptions of specific types of engineering careers related to specific WaterBotics "missions" as well as numerous links to external websites that also highlight engineering and engineering careers (McGrath & Sayres, 2012).

Research Questions

WaterBotics ex-post facto data were analyzed to answer the following research questions:

1. Do educators with engineering backgrounds have a greater effect on middle and high school student understanding of the engineering design process than educators without engineering backgrounds, as measured through pre and post student questions?

   1A. Does the magnitude of the effect vary by the discipline of the non-engineering instructor?
   1B. Does the magnitude of the effect vary by the background of the educator and the number of years the educator has been teaching?
   1C. Does the magnitude of the effect vary by the background of the educator and the students'gender?
   1D. Does the magnitude of the effect vary if the students were taught in a formal or informal educational environment?

2. Do educators with engineering backgrounds have a greater effect on middle and high school students' understanding of engineering careers than educators without engineering backgrounds as measured through a student "pile sort" instrument?

   2A. Does the magnitude of the effect vary by the discipline of the non-engineering instructor?
   2B. Does the magnitude of the effect vary by the background of the educator and the number of years the instructor has been teaching?
   2C. Does the magnitude of the effect vary by the background of the educator and the students' gender?
   2D. Does the magnitude of the effect vary if the students were taught in a formal or informal educational environment?

Participants

Data were collected from 2,455 students and 81 educators who participated in the WaterBotics program. Below are the statistics pertaining to WaterBotics educators and students who provided pre and post data.

Table 1
Number of Educators and Students who participated in WaterBotics

Educators	81
Students	2455

Table 2
Gender of Educators and Students

	Female	Male
Educators	46 (56.8%)	35 (43.2%)
Students	1090 (47.6%)	1199 (52.3%)

Table 3
Number of WaterBotics Students who Participated in Formal and Informal Learning Environments

Formal Learning Environment	1506 (61.4%)
Informal Learning Environment	945 (38.6%)

Educators who participated in WaterBotics were self-selected. Both formal and informal educators signed-up to learn how to facilitate WaterBotics through two successive National Science Foundation grants that provided professional development training on the WaterBotics curriculum, materials to implement WaterBotics, and follow-up support.

Student participants of formal educators were indirectly selected from the educators' student populations. Students of informal educators were self-selected for the WaterBotics camps and after-school programs.

Data Collection Instruments

There were two surveys and two data collection instruments utilized in this study (see Table 4):

Table 4
Surveys and Instruments

Survey or Instrument	Description
Survey 1	Educator pre-survey
Survey 2	Student pre-survey
Instrument 1	Student pre and post questions pertaining to student understanding of the engineering design process
Instrument 2	A pre and post “pile sort” assessment instrument pertaining to student understanding of engineering and engineering careers

All surveys and instruments were created for the WaterBotics curriculum by the external evaluator of the WaterBotics program, Dr. Susan Lowes, Director of Research and Evaluation, Institute for Learning Technologies, Teacher’s College at Columbia University. The surveys and instruments used in this study were designed specifically to align with content of the WaterBotics curriculum.

Survey 1: Educator Pre-surveys

Online educator pre-surveys were utilized to collect basic information about the educators who facilitated WaterBotics programs. Although the survey included many questions, the survey questions used in this study included “what is your highest degree?” and “what was your subject area, major, or field of study?” as well as “how many years have you taught?” These questions were asked to both formal and informal WaterBotics educators.

Survey 2: Student Pre-surveys

Online student pre-surveys were utilized to collect basic information about the students who participated in WaterBotics. Although the pre survey included many questions, the questions used in this study determined the gender and grade of the students. Student answers to survey questions were cross-referenced with educator data.

Instrument 1: Student Pre and Post Questions of the Engineering Design Process

To determine what students knew about the engineering design process before and after participating in WaterBotics, the researcher utilized recall questions from student pre and post surveys. The questions determined if students changed how they recapitulated the steps of the engineering design process pre and post the WaterBotics program.

To complete each “mission” in WaterBotics, students were encouraged to work through the Engineering Design Process (EDP). Not just a tool for engineering education, the EDP is “central to most forms of engineering” (Hynes, 2012, p. 346). The WaterBotics curriculum and educator professional development reinforces the iterative nature of the EDP and encourages students to follow its steps while creating underwater robots. The provided EDP used in the WaterBotics curriculum, Figure 2, included five steps:

(1) identify the problem,
(2) research and brainstorm,
(3) design and build,
(4) test and evaluate, and
(5) redesign.

Student handouts were provided that discussed each step of the EDP.

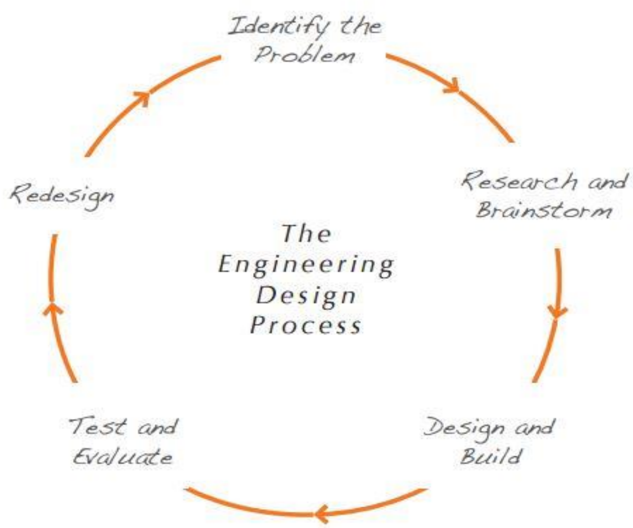


Figure 2. The Engineering Design Process used in the Curriculum (www.waterbotics.org)

Student understanding of the EDP was gleaned from the pre-survey question: "Do you know what the engineering design process is?" Answers were scored from 0 to 8, based on how many of the terms (which are included in the five steps of the EDP) that students included in their answers to the prompt, "If yes, give a brief description." Correct answers included (1) "identify the problem" or "state the problem," (2) research, (3) brainstorm, (4) design, (5) build, (6) test, (7) evaluate, and (8) redesign. The post survey question asked, "What is the engineering design process? Define it." This question was scored in the same way, from 0 to 8.

It should be noted that the survey questions were not initially intended to be used in the manner in which they are used in this ex-post facto study and can be questioned as an accurate measure of student understanding of the EDP. The limitations of the surveys and the way they are used as a measure of student understanding of the EDP are discussed in the Limitations section of this paper.

Below are the number and percentage of the responses to the pre-survey question, "Do you know what the engineering design process is?" These data excluded students who did not respond to the question.

Table 5

Number and Percentages of Student Pre-Survey Responses Pertaining to the Question "Do You Know What the Engineering Design Process Is?"

Student responses to the question "do you know what the engineering design process is?"	Number of student responses and their percentages
No	698 (29.2%)
Not Sure	1317 (55.0%)
Yes	376 (15.7%)

As Table 5 indicates, the majority of students (more than 84%) did not know or were not sure what the engineering design process was before their participation in the WaterBotics program.

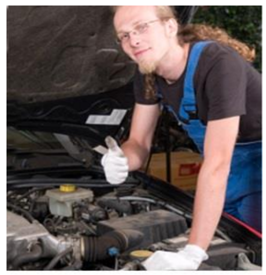
Instrument 2: Student Pre and Post "Pile Sort" Assessments of Engineering and Engineering Careers

The pile sort instrument (used to determine understanding of who engineers are and what engineers do) was jointly developed by Lowes and the WaterBotics curriculum developers and was piloted with thousands of students. It is considered locally developed and validated. The "pile sort" (a.k.a. card sort) activity (which started as a paper version "card sort" and then became a Flash-based digital version) was based on research by Spencer (2009) and utilized a limited number of cards. Students using the digital pile sort assessment were asked to "drag and drop" captioned pictures of people into one of three "piles": (1) engineers, (2) not engineers, and (3) "not sure." See Figure 3.

Figure 3. "Pile Sort" Assessment of Engineering Careers

Create a system to
clean water

Figure 4. Example engineer card



Repair cars

Figure 5. An example of a card that is “not an engineer”

Lowes created the pile sort as an assessment tool and indirect measurement of engineering careers in the WaterBotics program. As Lowes and Tirthali (2012) explained, “card sorts (or pile sorts) are used by ethnographers and cognitive scientists as an indirect way to elicit semantic or cognitive categories by having the sorter place items in different piles based on their similarities or differences” (Lowes & Tirthali, 2012, p. 7). The cards of the pile sort were created from research by Cunningham et. al. (2005, 2006), who used a draw-an-engineer test to ascertain misconceptions that students have about engineers. Lowes and Tirthali also used research by Fralick et al. (2009), who studied middle school students’ perceptions of engineering (Lowes & Tirthali, 2012, p. 7).

Regarding the “pile sort,” Lowes and Tirthali (2012) stated, “in pre-testing, students generally put many of the hands-on activities to do with cars, machines, and other trades into the engineer category (mechanic, electrician, heavy machinery driver, etc.), but they almost never put careers that involve systems or such activities as working in teams and researching in the library in that category” (Lowes & Tirthali, 2012, p. 7). Preliminary results from the Lowes and Tirthali study demonstrated that many of these misconceptions changed as a result of student's exposure to the WaterBotics curriculum (Lowes & Tirthali, 2012).

Procedure

This study utilized an seven-step procedure:

1. Query CIESE’s WaterBotics database.
2. Code the background data on the educators.

3. Eliminate records with missing data.
4. Score the EDP pre and post data.
5. Calculate the difference in pre and post EDP data as well as pre and post pile sort data.
6. Conduct analysis of the data using descriptive and inferential statistics.
7. Report findings.

Educator background data were coded into five categories based upon the reported undergraduate or graduate degrees of the WaterBotics educators. The five categories were a) engineering, b) science, c) mathematics, d) technology education, and e) other disciplines. Engineering degrees included industrial engineering, mechanical engineering, and electrical engineering. Science degrees included biology, chemistry, earth science, zoology, geology, marine biology, and veterinary anatomy. Mathematics degrees included mathematics and economics. Technology education degrees included industrial technology, integrative STEM, instructional technology, and technology education. Other disciplines included psychology, education, nursing, criminal justice, counseling, humanities, and educational leadership.

Data Analysis

This study examined ex-post facto WaterBotics data to determine whether educator backgrounds, specifically holding undergraduate and graduate degrees in engineering, influenced student understanding of the engineering design process and careers in engineering (i.e., of who engineers are and what engineers do).

To answer research questions one and two, the researcher analyzed and interpreted educator and student data using descriptive and inferential statistics. Inferential statistical analysis included univariate analysis of variance (ANOVA) tests.

To measure magnitude, the researcher utilized post-hoc Eta Squared tests, which helped to determine the effect size based on the discipline of the non-engineering educators, the number of years the educators taught before teaching WaterBotics, and differences based on gender and whether or not the educators taught in formal or informal educational environments. Levene's test of homogeneity, also known as the equality of error variances, was also used for statistical analysis of all univariate ANOVAs in which a main effect had unequal populations. Levene's tests helped determine the differences in variance between the studied populations.

Results

Data were collected from 2,455 students and 81 educators who participated in the WaterBotics program. Below (Table 6) are the number of WaterBotics educators and students in relation to the educator's backgrounds (i.e., undergraduate and graduate degrees):

Table 6

Educator and Student Populations of WaterBotics Program Grouped by Discipline of the Educators

Educator Background:	Engineering	Science	Math	Tech. Ed.	Other Disciplines
Educators	13 (16.0%)	18 (22.2%)	8 (9.8%)	10 (12.3%)	32 (39.5%)
Students	670 (27.3%)	584 (23.8%)	278 (11.3%)	352 (14.3%)	568 (23.1%)

Unique characteristic of WaterBotics educators:

- 16% (13 of the 81 educators) had backgrounds (undergraduate and graduate degrees) in engineering.
- The only group of WaterBotics educators comprising more males than females was the group of educators with backgrounds in engineering.
- More than 50% of all WaterBotics educators had taught for more than 7 years.

Below is a comparison of WaterBotics educators with backgrounds (undergraduate and graduate degrees) in engineering, science, mathematics, technology education, and other disciplines by gender and number of years of teaching experience.

Table 7

Gender and Years of Experience of WaterBotics Educators Grouped by Educator Discipline

Educator Background:	Engineering	Science	Math	Tech. Ed.	Other Disciplines
Gender of educator	Female: 38.5% Male: 61.5%	Female: 77.7% Male: 22.3%	Female: 75.0% Male: 25.0%	Female: 50.0% Male: 50.0%	Female: 38.5% Male: 61.5%
Years of experience as an educator	1-6: 41.6% 7+: 58.3%	1-6: 44.4% 7+: 55.6%	1-6: 37.5% 7+: 62.5%	1-6: 40.0% 7+: 60.0%	1-6: 45.5% 7+: 54.5%

The table below (Table 8) is organized by the backgrounds of the WaterBotics students' educators. The differences include student gender, whether or not the students learned WaterBotics in a formal or informal learning environment, and student responses to the WaterBotics pre-survey question, "Do you know what the engineering design process is?"

Table 8

Student Gender, Whether or not Students were Taught WaterBotics in a Formal or Informal Learning Environment, and Student Pre-survey Responses to "Do You Know What the Engineering Design Process is?" Grouped by Educator Discipline

Educator Background:	Engineering	Science	Math	Tech. Ed.	Other Disciplines
Student Gender	36.8% Female 63.2% Male	53.6% Female 46.4% Male	52.0% Female 48.0% Male	46.0% Female 54.0% Male	51.8% Female 48.2% Male
Students taught in Formal/ Informal learning environments	47.7% Formal 52.3%Inform.	64.5% Formal 35.5%Inform.	73.3% Formal 26.7%Inform.	89.9% Formal 11.1%Inform.	50.8% Formal 49.2%Inform.
Know EDP Prior to WaterBotics Program?	26.3% No 55.0% Not Sure 18.7% Yes	30.4% No 59.7% Not Sure 9.9% Yes	40.5% No 45.8% Not Sure 13.7% Yes	22.4% No 49.8% Not Sure 27.8% Yes	29.5% No 57.9% Not Sure 12.6% Yes

Three of the educator background groups above had a more than 50% female participation rate, including students whose educators had backgrounds in science, mathematics, and other disciplines. This is a relatively high number of female students for a robotics program. For comparison, FIRST Robotics Competition, for example, has a 30% female participation rate (Center for Youth and Communities, 2011).

Educators with backgrounds in technology education had the highest percentage of students who were taught WaterBotics in a formal learning environment (89.9%). This might be due to the fact that WaterBotics is easier to implement in traditional technology education programs than in traditional science, mathematics, or other classrooms. WaterBotics educators with backgrounds in technology education also had the highest "yes" response rate to the student pre-survey question, "Do you know what the engineering design process is?" One possible reason is that many technology educators already teach the engineering design process as part of their curricula.

Significant Findings from Research Question 1

A one-way ANOVA was utilized to determine the effect of the main factor – educator background (undergraduate and graduate degrees in engineering and all other disciplines) and the interaction between the groups as related to the dependent variable – student understanding of the EDP (measured by differences in pre and post responses). Results indicate that educator backgrounds did not have a statistically significant effect on student understanding of the engineering design process. However, when investigating research question 1A (see Table 9) - *Does the magnitude of the effect vary by the discipline of the non-engineering instructor?* -

ANOVA results indicated that the main effect, educator background, had a statistically significant effect on student understanding of the EDP at the P=<.05 level (df=4, 2451; F=4.97; p<.001).

Table 9

The N, Mean, and Standard Deviation for Students of Educators of Engineering, Mathematics, Science, Technology Education and Other Disciplines for Research Question 1A

Engineering	Science	Math	Tech. Ed.	Other Disciplines
N = 672	N = 587	N = 278	N = 352	N = 569
Mean = 1.570	Mean = 1.598	Mean = 1.381	Mean = 1.957	Mean = 1.956
SD = 2.033	SD = 2.017	SD = 1.745	SD = 3.355	SD = 2.341

To determine magnitude (i.e., effect size), the researcher utilized Eta Squared. This yielded a value of 0.008053, meaning that only 0.8% of the variance could be accounted for by the treatment effect, which was educator background, so caution should be taken interpreting these results.

Interestingly, educators with backgrounds in technology education had not only the highest mean difference between their students' pre and post scores of the EDP, but they also had students with the highest mean pre scores for the EDP as well.

Table 10

Mean Pre Scores of the EDP Question by Educator Discipline

Educator Backgrounds	Student scores of pre survey responses to the EDP question
Engineering	.29
Science	.12
Math	.24
Technology Education	.74
Other Disciplines	.25

These results run counter to research suggesting that when teachers have majors in their subjects, it significantly enhances student achievement in those subjects (Chaney, 1995; Rowan, Chiang, & Miller, 1997; Wenglinsky, 2000). The results from research question 1B demonstrated that students of educators with backgrounds in engineering performed well below average in their understanding of the EDP. Students of educators with backgrounds in technology education had the highest mean scores despite also having the highest pre-test score.

An unexpected result was how well students of educators from disciplines outside of engineering science, mathematics, and technology education performed. They had the second highest mean scores overall (only one one-thousandth of a point below students of technology education educators). A low post-hoc Eta Squared value from this study, however, indicated that the educator background variance between groups was small.

Other results from Research Question 1 included:

- Educators with backgrounds in engineering had the second-lowest mean score for understanding the engineering design process,
- Educators with backgrounds in technology education not only had the highest mean difference between student pre and post scores pertaining to the engineering design process, they also had students with the highest mean pre score of the engineering design process as well.
- Students of educators who hold degrees outside of STEM had the second-highest mean score of understanding the engineering design process.
- Females had statistically significant higher mean scores in understanding the engineering design process (df = 1, 2281; F = 8.939; p = .003).
- Younger educators (educators who taught 1-6 years prior to teaching WaterBotics) had higher student mean scores for understanding the EDP than older educators (educators who taught 7+ years).*
  *Not statistically significant

A Review of Raw Data from Research Question 1

A review of the raw student data of the EDP question ("do you know what the engineering design process is? If yes, give a brief description") revealed quite a few interesting results. For example, some students included the terms "trial and error" in both their pre and post responses to the EDP questions, suggesting that their WaterBotics educators may have used these terms as well. Notably, some of the students who used "trial and error" in their responses were students of educators with engineering backgrounds. One student of an educator who had a Master of Mechanical Engineering degree wrote, "The engineering design process is all trial and error," and another student of the same educator similarly wrote, "The design process *is* trial and error." Although the use of trial and error has its place in engineering, educators who attended WaterBotics training were encouraged to help students make informed design decisions using the EDP, not just use "trial and error." However, the use of LEGOs to build the underwater robots may have contributed to the student responses, as students may have utilized a trial and error method while rapidly prototyping with LEGOs instead of following every step of the EDP.

Other unexpected results from the raw data on the EDP questions were student responses stating that the EDP is "like the scientific method." Numerous students of one educator with a background in science responded this way. One wrote that the EDP is "basically the scientific method," demonstrating a lack of basic understanding of the EDP. These results also point to problems with fidelity of implementation of the WaterBotics curriculum, addressed in the Limitations section and revealed when one student wrote that the EDP is a "process of researching, designing, building, testing, modifying, etc.," while another student of the same educator wrote, "I don't think that was covered."

Significant Results from Research Question 2

Student responses to the pre and post pile sort instrument were scored from 0-16. The difference from post test score to pretest score was calculated for each student. Below in Table 11 are descriptive statistics for all WaterBotics students.

Table 11
The N, Mean, and Standard Deviation of the Pile Sort for All Students

	N	Minimum	Maximum	Mean	SD
EDP Scores	2233	-9.0	12.0	0.246	2.299

Student responses were grouped by the background of their educator: educators with backgrounds in engineering and educators with backgrounds all other disciplines (see Table 12).

Table 12
The N, Mean, and Standard Deviation of the Pile Sort Instrument for Students of Educators with Backgrounds in Engineering and Students of Educators that have Backgrounds in Other Disciplines

	N	Mean	SD
Pile Sort Scores of students of educators with backgrounds in engineering	664	-0.075	2.148
Pile Sort Scores of students of educators with backgrounds in other disciplines	1569	0.382	2.348

ANOVA results indicate that the main effect, educator background, had a statistically significant effect on student understanding of careers in engineering, as measured by the differences in student pre and post responses using the pile sort instrument at the P=<.05 level (df = 1,2231; F = 18.623; p < .001).

Overall, students who had educators with degrees in engineering had *lower* mean scores on the pile sort than students of educators of all other backgrounds. The high F-value (F = 18.623) supports this statistically significant result.

Table 13 was generated for research question 2A - *Does the magnitude of the effect vary by the discipline of the non-engineering instructor?* A one-way ANOVA was utilized to determine the influence of the main effect, educator background (educators with undergraduate and graduate degrees in engineering, science, mathematics, technology education, and other disciplines) and the interaction between these groups on the dependent variable, student understanding of careers in engineering (as measured by the difference in pre and post responses to the “pile sort” instrument).

Table 13

The N, Mean, and Standard Deviation for Students of Educators of Engineering, Mathematics, Science, Technology Education and Other Disciplines for Research Question 1A

Engineering	Science	Math	Tech. Ed.	Other Disciplines
N = 664	N = 555	N = 205	N = 307	N = 502
Mean = -0.075	Mean = 0.135	Mean = 0.453	Mean = 0.198	Mean = 0.739
SD = 2.148	SD = 2.216	SD = 2.571	SD = 2.400	SD = 2.324

The results indicated that the main effect, educator background, had a statistically significant influence on the dependent variable, student understanding of careers in engineering (df = 4, 2228; F = 9.936; p < .001).

To determine magnitude (i.e., effect size), the researcher utilized Eta Squared that yielded a value of .0175, meaning that only 1.75% of the variance was accounted for by the treatment effect, educator background. Therefore, caution should be taken interpreting the results of research question 2A.

Students of educators with backgrounds in engineering had the lowest mean scores in the pile sort activity. It should be noted, however, that they also had the highest pre-test scores (see Table 14).

Table 14

Student Pre Score Means on the Pile Sort Instrument Grouped by Educator Discipline

Educator Backgrounds	Student pre score means on “pile sort” instrument to measure student understanding of careers in engineering
Engineering	9.10
Science	8.40
Math	8.36
Technology Education	8.53
Other Disciplines	8.46

Other results from Research Question 2 included:

- Educators with backgrounds in engineering had the lowest mean score for understanding engineering careers.
- Students of educators who hold degrees outside of STEM had the second-highest mean score understanding engineering careers.
- Female students of educators of every background (engineering, science, mathematics, technology education, and other disciplines) had higher mean scores than males in understanding engineering careers.*
- Educators who taught 1-6 years prior to teaching WaterBotics had higher student mean scores for understanding engineering careers than older educators (educators who taught 7+ years).*
  * Not statistically significant

Conclusions

Results of this study indicated that students of educators with backgrounds in engineering had the second-lowest mean scores for understanding the engineering design process (EDP) and the lowest mean score for understanding careers in engineering, and both results were statistically significant. These outcomes counter research suggesting that teachers with majors in their subjects significantly enhance student achievement, specifically in secondary mathematics and science (Chaney, 1995; Goe, 2007; Rowan, Chiang, & Miller, 1997; Wenglinsky, 2000). Caution, however, should be taken when interpreting these results, as there was high variance within the groups.

Students of educators who hold degrees other than in engineering, science, mathematics, and technology education had high mean scores in understanding both the EDP (highest mean score of the groups) and engineering careers (second-highest mean score of the groups). The educators in this group had backgrounds (undergraduate and graduate degrees) in various subjects, taught WaterBotics in both formal and informal learning environments, and were from numerous regions around the U.S., making it difficult to pinpoint why this group did so well comparatively. It might be that educators who do not have backgrounds in engineering but who are tasked with teaching engineering at the middle and high school level do a better job of "sticking to the script" of a given curriculum like WaterBotics. Again, however, there was high variance within the groups, so caution should be taken when interpreting these results.

Students of educators with backgrounds in technology education had the highest mean scores for the EDP questions. This group also had the highest number of students who were taught in formal learning environments. This is of interest because, overall, students taught in informal learning environments had higher mean scores. Furthermore, the results indicate that not only did educators with backgrounds in technology education do well teaching the steps of the engineering design process, their students also had the most previous experience with the EDP, as indicated by pre-survey questions (their students had the highest pre-test scores for the EDP questions). This might be because technology education educators teach the EDP most often within their formal classrooms.

Another trend in the results was that, overall, female students did better than male students. Females had statistically significant higher mean scores in understanding the EDP; although it was not statistically significant, female students of educators of every background (engineering, science, mathematics, technology education, and other disciplines) had higher mean scores than males in understanding engineering careers. One of the data sets that made WaterBotics interesting to investigate was the high percentage of females who participated. Over 47% of the students who participated in WaterBotics were female, which is unique for a secondary robotics program (for comparison, FIRST Robotics, another national secondary robotics program, has a 30% female participation rate) (Center for Youth and Communities, 2011).

Another interesting trend, albeit one that was not statistically significant, was that, on average, educators who taught for 1-6 years before teaching WaterBotics had higher student mean scores for the engineering outcomes than educators who taught 7+ years before implementing WaterBotics. This might be attributable to the idea that younger educators might have had more pedagogical training teaching engineering. Again, because the findings for educator experience were not statistically significant, this is only speculation.

Obviously, not all WaterBotics educators implement WaterBotics in the exact same way. Formal classroom educators might implement WaterBotics differently, for example, from informal educators. Furthermore, because the curriculum is 20-26 hours long, there is plenty of time for educators to teach and reinforce topics and concepts differently. Some might, for instance, teach and reinforce every step of the engineering design process while the students are designing and building their underwater robots while others might take a more hands-off approach and simply let students build. This is a possible explanation for both the variation of the mean scores for each group as well as the variance between the groups.

The results of this study supported a previous finding by Lowes and Tirthali (2012) pertaining to the pile sort instrument of the WaterBotics program. They deduced that while WaterBotics students

> [e]xpanded their conceptions of engineering careers, they also tended to over-generalize, thinking that almost any career might include engineering. This may have been in part because the card sort assessment encouraged this, but it may also be that the participants need to be given a way to determine how engineering careers differs from other types of careers. (Lowes & Tirthali, 2012, p. 3).

This might be the cause of the overall low student mean pile sort scores. It could be that students who participated in WaterBotics programs thought, after the program, that “engineers do everything.” Regarding WaterBotics, it is recommended that educators need to distinguish more explicitly between what engineers do and what engineers do not do.

Limitations

There were numerous limitations to this study including the surveys and instruments used, the various backgrounds of the educators and students, the environment in which the students were taught WaterBotics, and the overall fidelity of implementation of the WaterBotics curriculum.

Limitation: Surveys and Instruments

A major limitation of this study were the surveys and instruments used. The online pre survey EDP question was, “Do you know what the engineering design process is?” The pre-survey provided a drop-down check-box for “yes,” “no,” or “not sure.” The survey then asked, “If yes, give a brief description.” The online post survey question asked, “What is the engineering design process?” Neither the pre survey question nor the post survey questions, however, asked specifically for the steps of the engineering design process. This made scoring the student responses in an objective manner difficult.

Regarding the EDP survey questions, it cannot be determined whether students of educators who had low mean scores on the EDP questions actually understand the central role of the EDP in engineering. Student pre and post surveys were utilized to measure their understanding of the engineering design process, but they did not probe deeper into whether students truly *understand* the content. The survey questions merely tested a student’s ability to recapitulate the steps of the EDP. Furthermore, the data collected could not reveal whether students actually did a better job designing and building underwater robots using the EDP.

Although there are many different versions of the engineering design process in use in engineering education, in order to score the responses objectively, the terms from the WaterBotics Engineering Design Process had to be explicitly re-stated. The terms included the following: a) identify the problem, b) research and brainstorm, c) design and build, d) test and evaluate, and e) redesign. A few students stated “and then start all over” at the end of their responses, inferring “redesigning,” but because they did not use the words “redesign” or “redesigning,” they did not receive credit for their response. It should also be noted that although many students misspelled many of the terms, their responses still counted as long as these were spelled phonetically. For example, students wrote “desine” instead of “design.” Furthermore, many students did not respond to either the pre or post survey questions pertaining to the engineering design process and left the questions blank (especially in the pre-survey). “I forget” and “I don’t know” were common responses. There were numerous students, however, who listed all eight steps of the WaterBotics EDP in their post-survey responses.

The pile sort instrument was created to determine what students know about engineering careers (who engineers are and what engineers do). The curriculum, however, is more aligned with teaching students how to use the engineering design process to design and build underwater robots. Although there are numerous parts of the curriculum that help educators teach students about engineering careers (the “missions” are based on real world work of engineers, there are numerous videos of real engineers working, etc.), the educators may not have taught engineering careers explicitly. Furthermore, as previously stated, some students, after participating in WaterBotics, may have over-generalized, thinking that engineers do more than they do. This might have led to the low student pre and post mean scores.

Limitation: Educator Backgrounds

In this study, the background of educators was based specifically on educator undergraduate and graduate degrees. Although there are numerous studies linking teacher's undergraduate and graduate degrees to student achievement, particularly in mathematics and science (Chaney, 1995; Goldhaber & Brewer, 1997; Rowan, Chiang, & Miller, 1997; Wenglinsky, 2000), there are many characteristics, beyond subject matter knowledge, that are important for good teaching. For example, Darling-Hammond, stated that teaching requires high levels of general intelligence, familiarity with content pedagogy, understanding of learners and learning, and adaptive expertise (Darling-Hammond, 2000). Darling-Hammond and Sykes argued that flexibility, perseverance, concern for students, and enthusiasm might also be considered (Darling-Hammond, Sykes, 2003). Of course, pedagogical knowledge and content area knowledge are also important to effective teaching. Regarding educator backgrounds, the WaterBotics educator pre-survey data did not reveal what other qualifications the educators had prior to implementing WaterBotics. For example, how much professional development did the educators have beyond the WaterBotics program? Did any of the educators participate in professional development that included teaching engineering before their participation in the WaterBotics program?

Also, data were not collected on how many times each educator taught WaterBotics. Educators who spent more time teaching WaterBotics might have been able to hone their knowledge, content, and pedagogical skills more effectively than educators who only taught WaterBotics once or twice.

Limitation: Student Backgrounds

Although this study examined both pre and post student outcomes, there were many differences between the backgrounds of the students. The students' levels ranged from 6th grade to 12th grade. Some had previous knowledge of the engineering design process, although most did not: of all of the WaterBotics students, 83.4% said they did not know or were "not sure" what the EDP was before participating in the WaterBotics program. Some students may have taken prior robotics or engineering courses, for instance. These differences might have led to some of the variance between and within subject groups.

Limitation: Formal and Informal Learning Environments

A major limitation of the WaterBotics program stems from the differences between the informal and formal learning environments. Educators who teach in formal learning environments often have more constraints than those who teach in informal learning environments. For example, formal learning environments have to align the WaterBotics program with existing curricula and standards and often have greater time constraints (they may have to teach WaterBotics within one scheduled period a day, for example). They might also put a greater emphasis on assessment. Conversely, informal learning environments tend to be less rigorous and might be perceived by students, therefore, as "more fun."

Another important difference between formal and informal learning environments is how they recruit students. Students of formal learning environments may have been told to participate while students of informal learning environments may have signed up voluntarily. This might have had significant implications for this study's results. If the informal students (the majority of whom were female due to recruitment by the National Girls Collaborative Project) were self-selected, this might have skewed the results since self-selection may have indicated a greater interest in robotics specifically and engineering in general.

Limitation: Fidelity of Implementation

Many of the limitations above point to a fidelity of implementation problem. They may be attributable to the train-the-trainer model used for scaling-up WaterBotics to increase the total reach of the program. In the train-the-trainer model, CIESE staff trained hubsite staff and hubsite staff, in turn, trained formal and informal educators. This model might have contributed to educators implementing WaterBotics differently. These differences can been seen in the data insofar as it revealed large variations between both the groups of educators and the educators themselves. There were also large variations within the groups, as indicated by the Eta Squared and Levene's test results.

Recommendations

Foundational research by Chaney (1995), Goldhaber and Brewer (1997), Rowan, Chiang, and Miller (1997), and Wenglinsky (2000) has supported the concept that, specifically in secondary mathematics and science, content knowledge is paramount; i.e., "content is king." This study, however, demonstrates that, when it comes to engineering education at the middle and high school level, content knowledge may not be the most important. In this study, educators with backgrounds in engineering had students with some of the lowest mean scores of WaterBotics engineering outcomes while educators with backgrounds outside of STEM had some of the highest mean scores. This should alert human resource practitioners and school administrators that, when hiring at the K-12 level, backgrounds in engineering may not be necessary to teaching engineering if the teachers are provided with a tested curriculum and proper professional development. This also can inform institutions of higher education that are involved in educator pre-service training. Furthermore, as the Next Generation Science Standards are being implemented in states across the country, educators with general science backgrounds might be capable of teaching engineering adequately enough to meet the new standards. Moreover, it would be useful to assess studies by Darling-Hammond (2000) and others who suggested that other characteristics of educators might be equally or more important to teaching in general and specifically to teaching K-12 engineering. Some of these characteristics are general intelligence, familiarity with content pedagogy, understanding of learners and learning, and having adaptive expertise (Darling-Hammond, 2000).

Future Studies

Future studies might include further investigating the backgrounds of WaterBotics educators and looking for non-cognitive effects such as student attitudinal changes. For example, do educators with backgrounds in engineering change student interest in engineering or get them to take classes that might lead to careers in engineering? Preliminary studies of the WaterBotics program by Lowes and Tirthali (2012) indicated that over 60% of students had an increased interest in engineering due to their participation in WaterBotics. Diving deeper into this result both quantitatively (looking for differences in educator and student gender as well as formal and informal learning environments) and qualitatively (conducting interviews and focus groups with students and educators would help to inform the field of K-12 engineering education) is recommended.

Based on the results of this study, it would be interesting to investigate how the non-engineering WaterBotics educators engaged students in engineering. It would be informative to conduct a qualitative case study of all WaterBotics educators to investigate the ways that they taught the program. Looking at the teacher characteristics of educators who taught WaterBotics (and possibly, the way those characteristics are viewed by students) might help to determine what characteristics are most important to facilitating engineering lessons. Research questions might include: What “teaching moves” did the educators make? How did they teach the engineering design process? Did they emphasize every step of the EDP? How, exactly, did they emphasize or teach careers in engineering?

Another study that could be conducted using existing WaterBotics data would investigate the differences between female and male students as they completed the pile sort activity. Every time students placed cards from the pile sort into “engineers,” “not engineers,” or “not sure” categories, time-stamps of the data were recorded. It would be interesting to see if female students and male students responded similarly to the images on the cards, specifically regarding cards depicting female and male engineers. This might help to explain differences in how the genders perceive engineers.

It is important for WaterBotics programs to continue to work with groups that are under-represented in engineering careers, specifically females, African Americans, and Hispanics. Therefore, it is recommended that, going forward, racial and socio-economic data on WaterBotics students be collected and analyzed. It is also recommended that future studies focus on schools and informal learning programs set in urban and rural areas that, traditionally, have provided few opportunities for students to learn engineering.

Another interesting research opportunity would be to look longitudinally at WaterBotics students. Such research might include investigating the coursework, colleges, and careers that students choose after participating in a WaterBotics program.

Finally, in a study titled The Status and Nature of K-12 Engineering Education in the United States, Katehi, Pearson, and Feder (2009) state the following:

> There are no pre-service initiatives that are likely to contribute significantly to the supply of qualified engineering teachers in the near future. Indeed, the “qualifications” for engineering educators at the K-12 level have not even been described. Graduates from a handful of teacher preparation programs have strong backgrounds in STEM subjects, including engineering, but few, if any of them, teach engineering in K-12 schools.
>
> To address this major gap, the committee suggests that the American Society of Engineering Education (ASEE), through its division of K-12 and Pre-College Education, begin a national dialogue on preparing K-12 engineering teachers to address the very different needs and circumstances of elementary and secondary teachers and the pros and cons of establishing a formal credentialing process. (Katehi, Pearson, & Feder, 2009, p. 2)

The results of this study have contributed to the concepts advocated by Katehi, Pearson, and Feder. It can be argued that educator backgrounds (i.e., their undergraduate and graduate degrees) do not need to be rooted in engineering, or any STEM discipline for that matter, for K-12 engineering education to be effective. Instead, educators need formal professional development in engineering content and pedagogy as well as effective curricula.

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