Using fluid power workshops to increase STEM interest in K-12 students

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USING FLUID POWER WORKSHOPS TO INCREASE STEM INTEREST IN K-12 STUDENTS

1. Abstract

This study addresses the issue of using robotics in K-12 STEM education. The authors applied intrinsic motivation theory to measure participant perceptions during a series of robotic workshops for K-12 students at Purdue University. A robotic excavator arm using fluid power components was developed and tested as a tool to generate interest in STEM careers. Eighteen workshops were held with a total number of 451 participants. Immediately after the workshop, participants were provided with a questionnaire that included both quantitative and qualitative questions. Fourteen of the questions are quantitative, where a participant would characterize their after-workshop experience using a 1 to 7-Likert scale. According to the intrinsic motivation theory it was hypothesized that participant perceptions should differ depending on their gender, race, and age. Inferential statistical analysis, ANOVA, was used to answer this research question and test that hypothesis. In order to be able to conduct relevant ANOVA testing the number of participants chosen for the test was reduced to a sample of 159 so that all groups were standardized. The general ANOVA test, applied to this sample number established that robotic-oriented activities in K-12 STEM classrooms have positive influence on student interest in STEM disciplines, and can be used to motivate them to pursue careers in related fields.

2. Introduction

In the current STEM education environment it is crucial for teachers and instructors to provide students with real life applications of the theoretical topics discussed in class. Using robots in STEM education is beneficial for attracting more students into STEM fields, and to encourage them to remain on a STEM career path. Three distinct advantages of using robots in STEM recruitment include: 1) improved student perception in STEM disciplines, 2) expanded student interest in choosing STEM careers among students, 3) better student retention rates throughout STEM career paths. Robotics present a unique advantage as engineering teaching tool because it can be used to explain basic concepts in mechanics like Newton’s laws but can also be used for explaining more involved topics like electronics, hydraulics or programming.

The broad goal of this project was to increase awareness of STEM fields; and particularly, the discipline of fluid power among young students attending middle and high schools. The data presented here was collected during a series of workshops that used a hydraulic robotic micro-excavator. Over 400 middle and high school students visited the Agricultural and Biological Engineering workshops at Purdue University between 2009 and 2011. The data was collected and analyzed to learn about students’ perception and motivation to pursue a career in a STEM field after completing the workshops. While some students participating in these workshops opt voluntarily to participate, many did not have the option to choose, and had no previous knowledge of the topics presented in these workshops.
3. Literature Review

Research on the use of robotics in the classroom can be divided into four major groups a) practitioner’s experience, b) research-oriented, c) robotics competitions, and d) workshops (for students, teachers or both). However, there are many intersections within these groups, as seen in “Attracting students to engineering through robotics camp”, where the authors include more than one category. Nordstrom et al. reported receiving data from both students and teachers during the workshops they held in Boston Public Schools. Of the literature surveyed for this study, there were a total number of four articles clearly identified as research-oriented. Most literature, however, focuses on documenting the practitioner’s experience, and highlights the practical applications of robots in STEM education classrooms.

Kolberg et al. claim that “modern technology is system oriented and integrates several disciplines” when talking about benefits of robotics curriculum in STEM classrooms. Wedeward et al. do not directly mention the systematic nature of robotics in education while stating that their robot kit provides “a basis of studies in math, physics and computer programming”. Nordstrom et al. emphasize the multidisciplinary nature of robotics that “makes it a natural tool for science and engineering education at many levels”. Weinberg et al. consider the possibility and the growing popularity of using robotics in all disciplines including liberal arts studies, thus highlighting the systematic nature of robotics.

An after-workshop questionnaire was employed in this study to obtain student perceptions and interests in STEM fields. The goal was to determine if exposing the students to a robotic workshop would influence them to consider a career in a STEM discipline.

The questionnaire used a Likert scale for the intrinsic motivation inventory (IMI) assessment proposed in McAuley et al. IMI is used to measure participants' subjective experience as it is related to a specific activity in a laboratory setting, or as in our case, the robotics workshop. The questions in this survey measure four major dimensions of internal, or intrinsic, motivation. These dimensions are 1) interest/enjoyment, 2) perceived competence, 3) effort/importance and 4) tension/pressure. The questions listed in the appendix are based on these four dimensions. With this questionnaire the intention was to measure the impact that the robotic workshop had on the students perceptions in these four areas.

The main hypothesis of this work is that Problem Based Learning (PBL) can influence students to be interested in STEM disciplines. PBL assumes that in the learning process the student takes an active role. In PBL the focus is centered on challenging students to be participants of their learning process by solving a problem that is generally open ended. In the particular case presented in this work, the students were presented with a robotic arm with missing connections, In it, the students had to collaboratively find a solution to the presented problem to make the robot work.

Several researchers have studied the motivational effect of robotics to encourage students to pursue STEM careers. Specifically, Nordstrom et al. mentioned that “not a single camper reported a decrease in any of these areas – STEM – as a result of attending robotics camp.” Fiorini et al. report taking “advantage of the appeal of this subject on the students” in
order to start developing robotics curricula for high schools. Of these articles, Weinberg et al.\textsuperscript{3} provides the reader with likely the most complex and rigorous research on the topic. They focus on the differences in perceptions of boys and girls while implementing the same tasks. Using a series of ANOVA studies, Weinberg et al.\textsuperscript{7} discovered an increase of interest and a shift from traditional gender roles following the robotics-involved class activities. One of the other questions Weinberg et al.\textsuperscript{3} addresses is the impact of robotics experience on girls’ attitudes towards STEM as a possible development of their careers. Other research confirms this result\textsuperscript{12,13}. The research cited on this particular topic of women choosing STEM careers can help academic institutions recruit women and other minorities to STEM programs. Overall, these studies support the premise that the perceptions of students of different gender and race can be impacted through robotics. This can help policymakers and administrators acknowledge the impact of robotics in K-12 classrooms, and make decisions that are more targeted and therefore more productive in terms of raising interest in STEM. It is interesting to note that among the retrieved articles, the topic of women and minorities in STEM was only a direct interest of just a few authors\textsuperscript{3,4}.

Finally, the last key point to consider is the cost of using robotics in STEM education and its evolution throughout the last two decades. Thanks to the computer revolution of the 1980s’, robotics kits have moved from being expensive toys to a practical learning tool in classrooms and schools. Robots, together with computers of all kinds, are becoming common place in contemporary classrooms and used to demonstrate practical applications of STEM principles. However, many authors especially emphasize the fact that robots have not yet become inexpensive enough for schools to afford purchasing them. As a result, the majority of researchers came up with their own robot kit for the STEM activities in the classroom\textsuperscript{5,6,10,11,14,15,16}. These kits were usually built from a combination of their own resources and commercial parts, with some researchers using commercially available robot kits such as the LEGO, FisherTecnik, FESTO, etc.\textsuperscript{11,17,18,19}. In general, the researchers developing a systematic approach to the use of robotics in the classroom appeared to use their own robot kits in the classrooms.

The literature surveyed here gives a broad range of the potential applications of robotics in the classroom. Several researchers include the whole STEM timeline, from pre-K to 12 and even undergraduate level courses as the potential settings for their robotic applications\textsuperscript{7,10,14,20}. Others prefer to concentrate on some concrete level, or activity, such as a vocational course\textsuperscript{5}, summer program\textsuperscript{6}, various undergraduate courses\textsuperscript{17,21,22} or middle-school environments\textsuperscript{4}, robotic competitions\textsuperscript{23,24,25,26}, and workshops at different levels\textsuperscript{4,16,27,28}. Workshops as a form of activity have become the basis for the research presented here. The objective of this research is to present an analysis of the data gathered to measure interest in STEM careers of middle and high school students after visiting the research facilities at Purdue University.

4. Research Question and Hypothesis

This work builds upon existing research by asking the following research question, and testing the hypothesis through the use of student surveys completed at the end of the outreach activities:
Research question:
- How do Problem-Based Learning (PBL), fluid power focused, activities influence middle- and high school student interest in STEM disciplines?

Hypothesis:
- PBL fluid power activities equally influence middle - and high school students regardless of the gender, race, and age distribution of the participant groups they represent.

5. Workshop Procedure

In the workshops almost all students had no previous knowledge of hydraulics or pneumatics, the students interacted with the micro-excavator demonstrator shown in fig.1. A typical interaction time with the micro-excavator was 30-minutes in length.

In these workshops students were briefly introduced to hydraulics and pneumatics in a 5-minute presentation. In it, they were told the basic components of a fluid power system and their function. The students were also instructed on how to use the push-to-connect fittings of the robotic demonstrator to connect the components using plastic tubing. After the 5-minute introduction was finished the students were divided into groups of four or five per demonstrator and were given a handout that shows a hydraulic or pneumatic schematic on how to connect the components to successfully operate the demonstrator.
After finishing the exercise the students were given the task of moving the arm and compare it to the ISO control pattern used in excavators and shown in fig.2. Lastly the students were asked to modify their system to match that of the ISO pattern. After completing the workshop, the students were asked to complete the questionnaire, in it, they were asked to express their impression about the demonstrator and the activity as a potential tool for science education in their respective schools.

The workshop activity was offered to multiple groups of students. Most students were able to successfully connect the components as described in the handout. The majority of participants had positive comments when asked about the value of the demonstrator and the workshop activity. Most students said their favorite part of the activity was the hands-on requirement to connect the components in the excavator and being able to dig with the excavator when they were finished with the assembly. The questionnaire was intended to measure the level of internal motivation of the students after the workshop using a Likert psychometric scale ranging from 1 to 7.

6. After-workshop Questionnaire Description and Results Outline

In this research the primary data collection tool – the questionnaire – was specifically designed to answer questions regarding student experiences using fluid power to demonstrate STEM principles, as was stated in the research question in section 4.

The general questionnaire (see Appendix 1) contains 14 statements measuring the level of student involvement during a workshop as they report it by themselves on a scale from 1 to 7, with increments of 1, where 1 stands for Not at all true, 4 – for Somewhat true, and 7 – for Very true. A reported involvement of 7 implies maximum interest and low reported involvement of 1 implies minimum interest. The fact that the activities the students participated in were designed as STEM activities gives the researchers an opportunity to interpret student interest in those activities as their interest in STEM in general. However, the word STEM was not included in the
questionnaire in order avoid the bias, i.e. to make the responders concentrate on their perception of the activities themselves as opposed to their familiarity with the term STEM.

The list of questions used in the data analysis contained questions Q1, Q3, Q4, Q5, Q10, Q11, Q12, Q13, Q14 because these are the specific questions that measure interest level. Hence, the final total number of questions is nine. Future research will consider grouping the questionnaire data from the workshops under such parameters as difficulty level, value to schools, personal value, and others. Such range can potentially provide an opportunity to address even more questions as discussed in the literature review.

Figure 3 Distribution of student responses

A total population included 625 students surveyed, of which 319 were female and 232 were minorities. Figure 3 depicts the distribution of the student’s responses to the questionnaire (see appendix). The 14 questions in the survey were divided into nine areas used for quantifying intrinsic motivation. A great majority of the students claimed they enjoyed and were interested in the topics presented in the workshop activity. Moreover, on a scale from 0-7 students graded the activity as 5.3 for value and usefulness. The student’s interest in STEM careers after completing the workshop also similar score of 5.2 but had a standard deviation of 0.6.

Descriptive statistics of the data, i.e. histograms generated for each of the nine questions in all workshops demonstrated high interest in STEM fields among participants after the respective workshops. Such result supports the original statement (suggested in the literature review as well) that robotics activities have a positive influence on middle- and high school students’ interest in STEM.

An interesting question that can be asked from the data is the value of student interest across workshops when grouped by different demographics. Taking into account that all groups of
participants were diverse, i.e. contained students of different genders, races and ages, the hypothesis was framed to address this issue. Since there were more than two groups of participants, a one-way (one-factor) ANOVA was used to evaluate the strength of the relationships between the different groups. The value of interest in STEM (post-workshop) is associated with each population of interest (i.e. students from a particular local school/area, etc.).

Questionnaire results are the sample values taken from those populations. The null and alternative hypotheses to be tested are:

\[ H_0: \mu_1 = \mu_2 = ... = \mu_9 \]
\[ H_1: \text{At least two of the population means are different} \]

Prior to the test procedure the data was tested to meet ANOVA assumptions, such as:

1. All populations are normally distributed
2. The population variances are equal
3. The sampled observations are independent
4. The data’s measurement is interval or ratio
5. \( \frac{n_{\text{max}}}{n_{\text{min}}} \leq 1.5 \) where: \( n_1 \neq n_2 \neq ... \neq n_9 \)

Condition 2 was met after excluding a few outliers; condition 4 was met as the data has intervals (1-7 scale). The sampled observations are independent (condition 3) as long as the participants from different workshops didn’t interact with each other before and immediately after the workshops and is expected to be generally met as students represented different schools and geographical regions.

In order to meet the 5th ANOVA condition we had to decrease the number of samples to 6 (out of 14) and the united sample size to 159 participants. This means that the number of samples or group had to have an approximate number of individuals such that the ratio of individuals between the largest group and the smallest group remained below 1.5.

The ANOVA test resulted in the rejection of the null hypothesis, i.e. it can be claimed with a 95% confidence level that the value of students’ interest after the STEM workshops was different across different groups of participants. Therefore, there are certain factors within those groups that can affect the value of interest. Based on the literature review these factors include, but are not limited to, participants race, gender, and age.

7. Questionnaire Results and Conclusions

The analysis of general ANOVA results shows that the original hypothesis stating that there is no difference in student interest as impacted by their participation in the workshops can be rejected using a 95% confidence level.
The intrinsic motivation theory suggests that intrinsic interest should be different for the students of different races. In other words, what is motivational for Caucasian Americans will not be necessary motivational the same way for African Americans, Native Americans, Asian Americans or Hispanics. Further diversity-specific analysis can be conducted with the existing data to illustrate that the general ANOVA polygenic results are caused by at least one defining factor, such as the diversity of races within each sample, or workshop.

On the other hand, it can be assumed that both gender and age also added to the general ANOVA results as two additional differentiating factors. As discussed in the literature review section, existing research studies suggest that student interest in STEM generally varies depending on the gender of students. This means that it could also potentially be the case in the workshops held and the general ANOVA polygenic results indirectly support such idea.

School education level was the third parameter examined. Education level correlates to depth of STEM knowledge covered in each grade. This, at the same time, can affect their perception of workshop activities and the interest level by the end of a workshop. The literature reviewed in the introductory section highlights an existing pattern of the observed difference of student interest across different school levels, i.e. Elementary, Middle, or High schools. During the current study participants were from Middle and High schools, such that a sample of students per workshop was either from a Middle or High school. In other words, student didn’t mix across school levels. That data can be potentially useful at the next stage of the research.

8. Acknowledgement

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9. References

Overview: All surveys remain anonymous and are used to improve the quality of our programs. For each of the following statements, please indicate how true it is for you, using the following scale:

1 2 3 4 5 6 7
Not at all true Somewhat True Very True

<table>
<thead>
<tr>
<th>Question</th>
<th>Introduction to Fluid Power</th>
<th>Not / Some / Very</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I enjoyed doing this activity very much.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>2</td>
<td>I believe this activity could be of some value to me.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>3</td>
<td>I thought this was a boring activity.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>4</td>
<td>I think that doing this activity is useful for me to see fluid power as a possible area of study in college.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>5</td>
<td>I would describe this activity as very interesting.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>6</td>
<td>I found it difficult to grasp the concepts that were taught during this activity.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>7</td>
<td>I think doing this activity could help me to apply math and science to practical and everyday applications.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>8</td>
<td>I would recommend activities like this to be used at my school.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>9</td>
<td>I think this is an important activity.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>10</td>
<td>This activity did not hold my attention at all.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>11</td>
<td>I would be willing to do this again because it has some value to me.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>12</td>
<td>I think this is important to do because it stimulated my interest to consider a career in science, technology, engineering, or math.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>13</td>
<td>This activity was fun to do.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>14</td>
<td>I would like to build other systems, such as airplanes, automobiles, or manufacturing robots using similar components and methods.</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>
What was your most favorite aspect about this activity?

What was your least favorite aspect about this activity?

Demographics

I am: Female / Male (circle one) Age: ____________

I am: Asian / African American / Foreign / Hispanic / Native American / Other / White (circle one)