

## **Evaluation of an Energy and Engineering Outreach Program for High School and Middle School Students**

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## **Abstract**

The education and influence of students in the STEM fields has great importance in modern society, especially with our ever-increasing reliance on new technologies. Research collaboration between two universities engaged over 700 students and teachers. The authors designed engineering-based curriculum, hands-on lessons, and demonstrations that were focused on energy. The curriculum exposed students and teachers to fundamental science and engineering concepts. Many of the activities for these outreach activities engaged participants in a 3-tiered energy challenge by designing and fabricating prototypes that demonstrate: (1) Energy generation and conversion, (2) Increased energy efficiency, and (3) Energy use monitoring and control.

The design and physical modeling that was employed in the outreach events using energy technologies requires students and teachers to practice high-level thinking (e.g. analysis, synthesis, evaluation) in teams while building a culture geared toward energy technology innovation. The participants were introduced to concepts from traditional engineering curricula such as thermodynamics, fluid mechanics and dynamics, while working with principles of renewable and nonrenewable energy technologies used in industry, such as the photovoltaic effect. The student participants were given pre-tests and post-tests to evaluate the success of the outreach events in developing their awareness and understanding of energy and engineering, measure their level of engagement with the activities, and evaluate their attitudes towards teamwork. This paper will present the energy curriculum, hands-on energy laboratories, design and fabrication challenge and the results from the pre- and post-tests.

## **Introduction**

Times are changing. This is commonly referenced when speaking about technology and the younger generations. The attention span of students is shorter now than they were just 15 years ago [1]. As the world around us changes, it is essential that education techniques stay ahead of the curve. As a result this study set out to implement project based learning (PBL) techniques in order to grab students' attention and teach critical issues within engineering - energy and sustainability.

As sustainability becomes an increasingly vital component in all fields of engineering, it has become increasingly important to implement it into engineering curricula. Furthermore, current research shows that education methods that address the affective domain of students proves to be more effective than methods that otherwise do not [2].

With this knowledge, the research team planned to implement and assess a curriculum that consists of engineering design projects to teach sustainability and energy all while positively

engaging key areas of the affective domain. More specifically, a goal of this study was to evaluate changes in participant motivation, attitude, enthusiasm, interest, creativity and self-efficacy.

The research team implemented various aspects of the Energy Labs in 4 settings: 1) Manchester Academic Charter School (MACS) – an inner city school where we worked with students between 6<sup>th</sup> and 8<sup>th</sup> grade. 2) a two-day training program called Teach the Teacher that was developed and conducted by the University of Pittsburgh 3) a five-week summer course hosted by the University of Pittsburgh pre-collegiate diversity in engineering program called Investing Now and 4) a week long program at Robert Morris University called Energy Week that focused on energy and sustainability. Investing Now consisted of 30 eleventh grade students from underrepresented groups in STEM while Energy week served both a middle and high school student population that were predominantly white. This paper will focus on the results obtained from the surveys that were administered to the Investing Now students and the Energy Week students.

In developing our approach alongside the outreach events, seven key areas were identified to monitor. They are as follows:

- 1) *Attitude*: This focus area is included in an attempt to measure the effectiveness of the approach to change students' attitude to be more open to participation and engaging in engineering, energy and sustainability. The goal was to measure self-reported willingness to engage and examining resulting changes.
- 2) *Motivation*: This focus area requires tapping into both intrinsic and extrinsic motivations during implementation. While the overarching objective is to have the students leave the program with greater motivation to pursue engineering and focus on energy and sustainability we recognize that the individual motivation levels and motivators will vary, but the overall level of motivation should increase with teacher rapport.
- 3) *Interest*: The effectiveness of the program to develop and increase the overall interest for students to learn more about sustainability and energy within engineering. By the end of the program, students ideally should have a greater interest in the topics covered.
- 4) *Enthusiasm*: Enthusiasm is often positively correlated to attitude and motivation however; the former is often better defined as enjoyment while the latter reflects more on their reasoning and behaviors.
- 5) *Creativity*: This item is more abstract and its assessment will be discussed in another section. However, the intended gains in this area include develop a greater sense to design something unique and original.
- 6) *Self-Efficacy*: Self-efficacy has many of the above focus areas wrapped into it, but with a stronger connection to the students' confidence and anxiety to take on and complete

specific objectives in the field of sustainability, energy and the engineering design process.

- 7) *Competency*: to increase knowledge and understanding on specific subject matters. The goals for this study include increasing competency in the areas of energy, sustainability and engineering design.

### Methodology

In constructing the curriculum, a backwards design approach was utilized to allow alignment with the focus areas outlined in the introduction and determine the necessary assessments to produce results that can be used to measure the effectiveness in achieving the goals [3].

The backwards design approach/logic is depicted in Figure 1.



Figure 1: Backwards Design

The desired outcomes were listed as the seven key areas from the introduction section of this paper and thus determined the evidence needed to support those outcomes. The key areas to be evaluated were assessed using student surveys. Implementation would take place in the form of weekly assessments, pre-surveys and post-surveys. The pre-survey would ask questions in each of the key areas and would be used as a benchmark to determine the students initial attitude, motivation, interest etc. The weekly surveys and post-survey would be used to measure gains throughout the course. This paper will include results from surveys conducted on the Investing Now students and the Energy Week students.

Investing Now hosts their five-week summer course every year. Our program was built into their curriculum framework and restructured to meet learning objectives in the areas of energy, sustainability and engineering design with focuses on energy efficiency, renewable energy technologies and mechatronics. The final curriculum is outlined below, in Table 1.

The curriculum was designed to provide a gradual increase in design responsibility and creative autonomy. That progression is known to enhance students' self-efficacy [4]

Week 1	Introduction to engineering, design, creativity, energy and sustainability. Design Project: Model and prototype a wooden car that is designed in SolidWorks.
Week 2	Energy Efficiency, renewable energy, energy usage and sustainability Design Project(s): Solar oven design, windmill design
Week 3	Electronics and Energy usage Design Projects: Arduino circuits and Makey Makey controllers
Week 4 & Week 5	Open-Ended Design projects based on energy and sustainability.

Table 1: Investing Now Summer Program Curriculum Outline

Energy Week took place during the last week of July, 2015. The week was split into 2 sections where the first three days were dedicated to high school student activities and the last three days for middle school student activities. The schedule of activities is shown in Table 2 below. There were three activities for the High school students and two activities for the middle school students. While allowing the student to work on their projects, instructors periodically provided presentations and demonstrations with energy production, efficiency and controls as the major themes.

<b>High School Student Schedule</b>	<b>Middle School Student Schedule</b>
Day 1: July 27, 2015 <ul style="list-style-type: none"> <li>• Pre Survey</li> <li>• Global Warming Presentation</li> <li>• SolidWorks – MDF Cars</li> <li>• Build MDF Cars</li> </ul>	Day 4: July 30, 2015 <ul style="list-style-type: none"> <li>• Pre Survey</li> <li>• Global Warming Presentation</li> <li>• SolidWorks – Lego Car Assembly</li> <li>• Build Solar Lego Cars</li> </ul>
Day 2: July 28, 2015 <ul style="list-style-type: none"> <li>• Race the MDF Cars</li> <li>• SolidWorks – Lego Car Assembly</li> <li>• Build Solar Lego Cars</li> </ul>	Day 5: July 31, 2015 <ul style="list-style-type: none"> <li>• Arduino – Energy Monitoring and Control</li> <li>• Race Lego Cars</li> <li>• Solar Popcorn</li> <li>• Post Survey</li> </ul>
Day 3: July 29, 2015 <ul style="list-style-type: none"> <li>• Arduino – Energy Monitoring and Control</li> <li>• Race Lego Cars</li> <li>• Post-Survey</li> </ul>	

Table 2: Energy Week Summer Program Schedule

Due to the fact that this study involves assessing and evaluating human subjects, the Internal Review Board (IRB) was consulted. During the process, the IRB determined that this study would be classified under the “exempt” status because the evaluation methods (surveys and student report outs) were non-invasive and did not include identifying information. The IRB still required completion of the necessary online training modules prior to implementation.

## Assessments

In assessing the Investing Now students, a variety of questions and question types were asked to obtain metrics in each of the areas of interest. The initial questions asked in the pre-survey served as the benchmark to measure gains. As the course progressed, surveys were designed to ask questions that probe higher cognitive thinking by using words outlined in Bloom's Taxonomy. In the beginning, the questions assessed lower level skills such as knowledge and comprehension. By the end of the course, the students were asked questions on the highest level of Bloom's Taxonomy - evaluation [5].

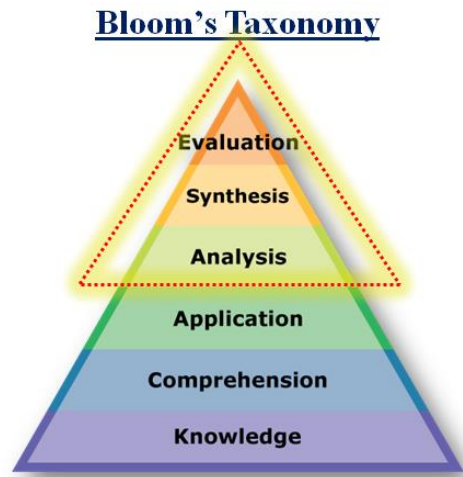


Figure 2: Blooms Taxonomy with Areas of Higher Level Thinking Highlighted

For example, the pre-survey included the following open-ended questions: “What is sustainability? Why is it important?” The first week survey asked, “If you had to explain sustainability to a friend, how would you explain it to them?” The second week then goes on to ask, “Describe how we can use solar energy to be more sustainable.” The pattern continues through week four and the post-survey.

The above questions are focused on competency in sustainability and similar questions were asked about the design process and energy while the other questions addressed the affective domain described previously. The pre-survey asked multiple self-efficacy questions about the engineering design process. The questions administered were inspired by the work performed by researchers from Tufts and Purdue Universities [6]. The questions asked for the students to respond with their degree of confidence, motivation and anxiety on a scale of 1-10 in nine subcategories (steps) of the engineering design process. Comparable questions were asked for the other focus areas of the human element. The assessment used for the students during Energy Week did not include weekly surveys due to time constraints and only included a pre- and post-survey. Examples of survey questions can be found in Appendix A.

### Results for Investing Now

The number of participants did not remain constant throughout the course as a result of student absences. At the time of the pre-survey, a total of 22 students were present. An additional student joined to bring the total to 23 students by the end of the first week when the week one survey was implemented. The number then decreased to 20 for both weeks two and three. The fourth week had a total of 19 participants and the final post-survey has yet to be conducted.

Each week students were asked to report if they learned about the week's topic (sustainability, energy and engineering). These are indicated as learning perceptions and helped to measure attitude/enthusiasm toward the subject matter.

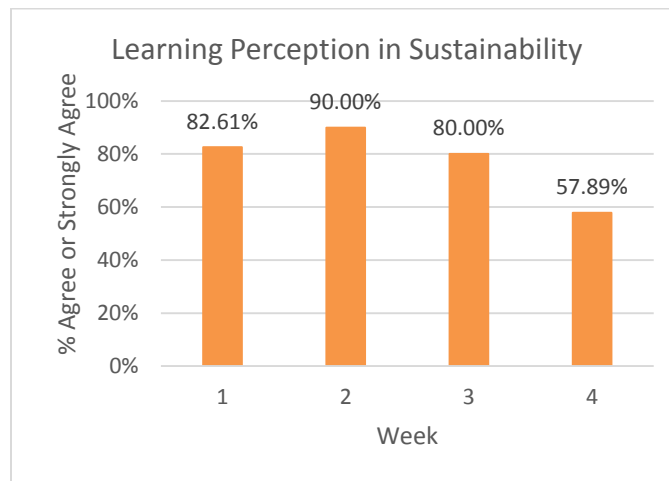


Figure 3: Learning Perceptions in Sustainability

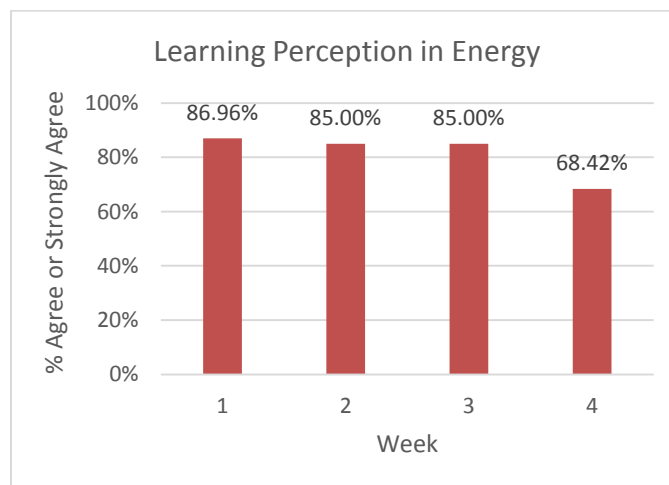


Figure 4: Learning Perception in Energy

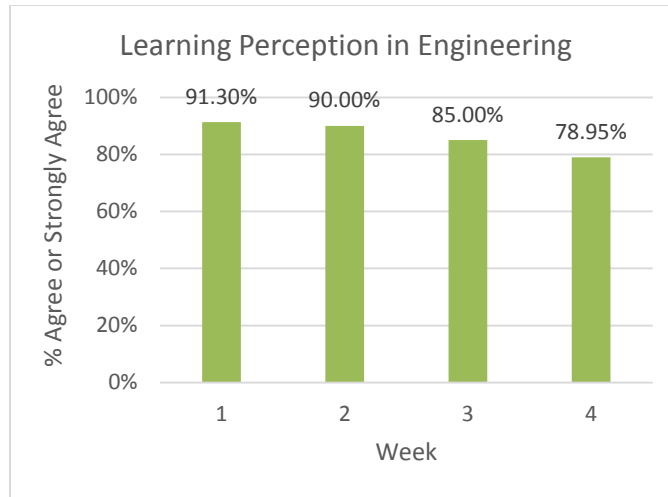


Figure 5: Learning Perception in Engineering

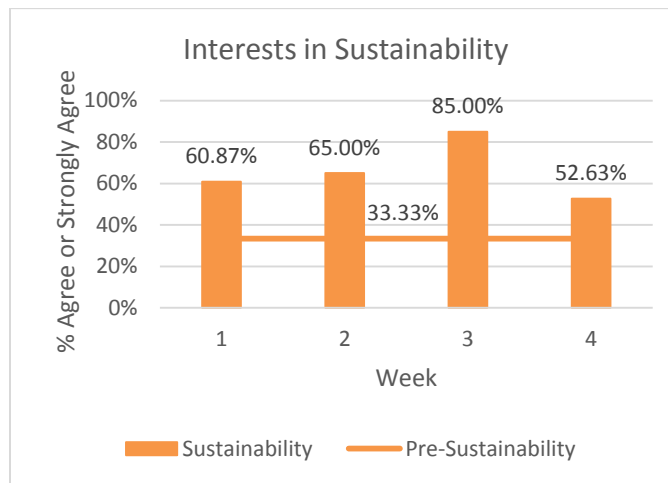


Figure 6: Interests in Sustainability

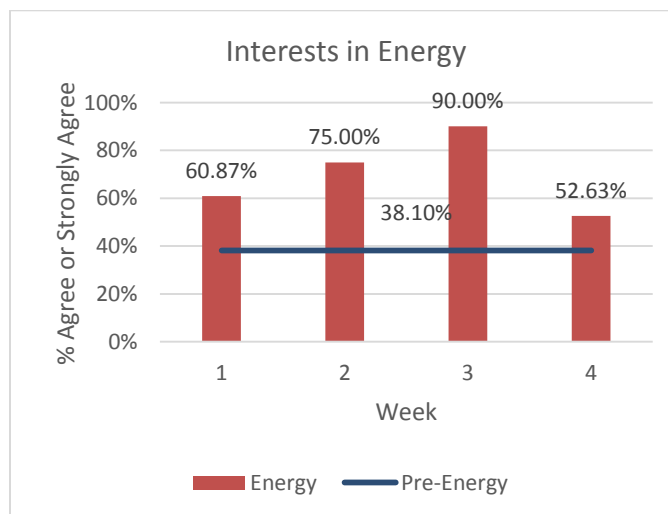


Figure 7: Interests in Energy



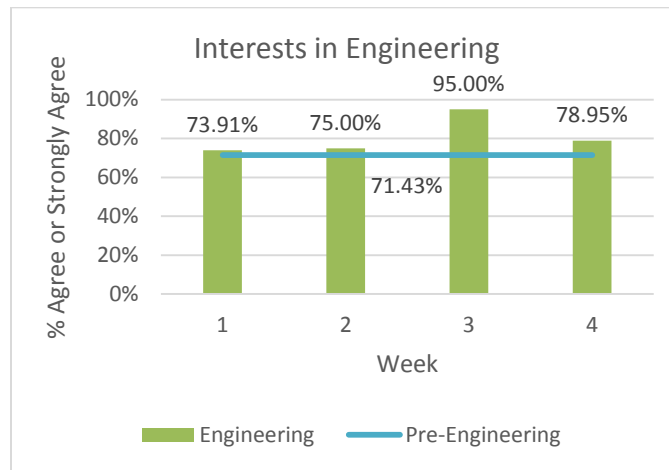


Figure 8: Interests in Engineering

The data used on for Figure 2 through Figure 7 were collected from student responses to Likert questions (scale: strongly disagree, disagree, neutral, agree or strongly agree). The percentages were calculated based on those that answered agree or strongly agree. For interests and learning-perceptions, the students were asked if they “learned more about...” or are “more interested in...” Those who answered neutral were considered combined with those who “disagreed” or “strongly disagreed” such that the data would only reflect those who had an increase in each of the specific areas that were being measured.

One conclusion from the data is based on the fact that week 4 results are lower than week 3. The fourth week did not have any lectures or presentations from the facilitators, the entire week focused on the students working on their chosen design projects. From that, a preliminary conclusion seems to be that students need some guidance when working with hands-on design projects to fully grasp the concepts that are being taught. To make up for the decrease in all areas in week 4, the team plans to make the students present on their projects and ask them to speak on sustainability, energy and engineering. The intent is that this report out will help the students put their projects in perspective and help them see the larger picture in regards to the three topics listed above.

Some other areas of the affective domain can also be found in Figure 9 through Figure 11. These three areas are Engagement, Motivation and Enthusiasm. These questions were asked in a similar fashion to the questions described above. A Likert scale was used, however, the questions were about the specific design challenge. The questions were asked of the specific design challenges to tie the development of these areas back to sustainable design projects.

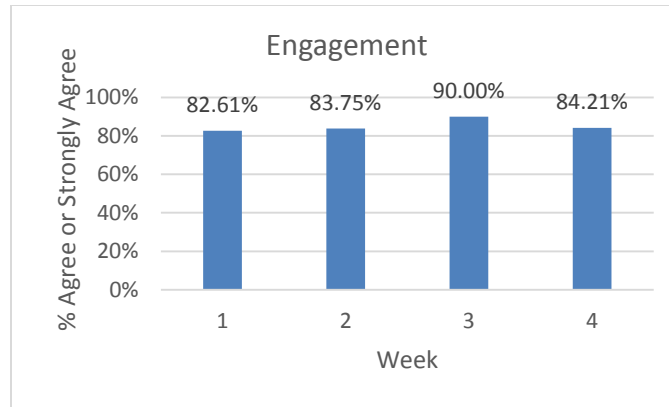


Figure 9: Student Engagement from Design Challenges

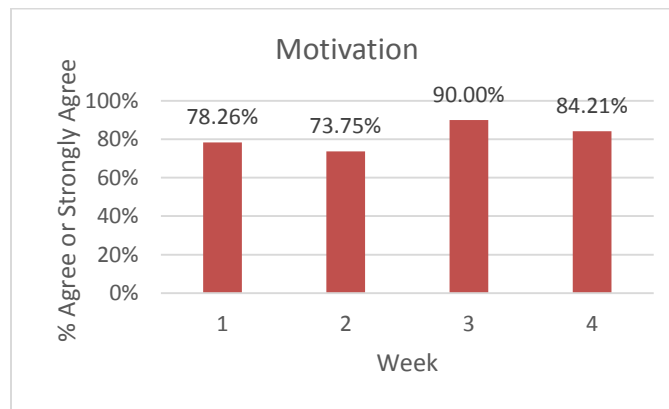


Figure 10: Student Motivation from Design Challenges

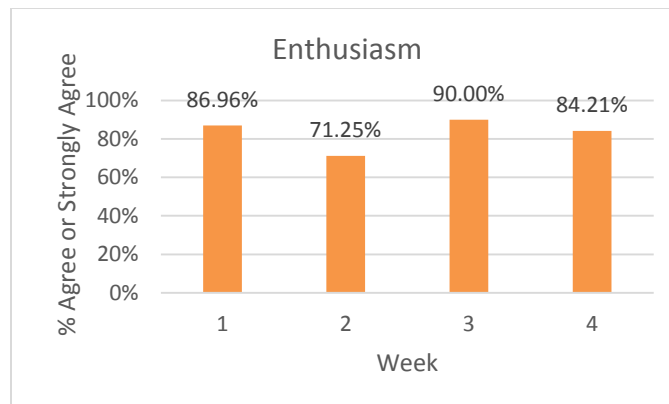


Figure 11: Student Enthusiasm from Design Challenges

### Results for Energy Week

The number of participants in the high school group (the first three days of the week) varied by 1 from the first day until the last and therefore we recorded 15 participants for both the pre-survey and 14 for the post-survey. There were two students that did not show up on the second of two days in the middle school group, so we recorded 19 participants for the pre-survey and

17 participants for the post-survey. The students were asked questions about motivation, confidence, interest, and teamwork as they are related to energy, engineering and design. The answers were all recorded using a Likert scale from 1 to 5, as shown below. Figure 12 gives a percentage breakdown of the student participants in Energy Week. As we can see, ninth grade students made up the majority of the high school participants and seventh grade students made up the majority of the middle school participants.

Likert Scale:

- 1 = Strongly Disagree
- 2 = Disagree
- 3 = neither Agree nor Disagree
- 4 = Agree
- 5 = Strongly Agree

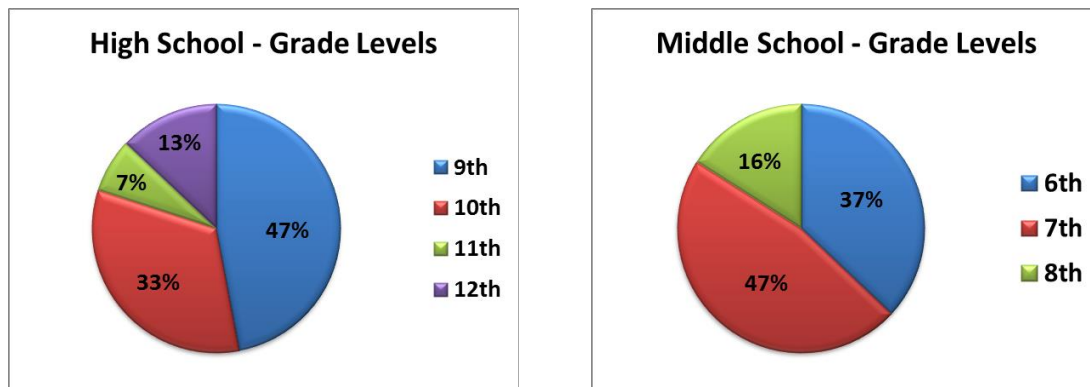


Figure 12: Breakdown of the Grade Levels that Participated in Energy Week

Below are the results from the high school participants in the pre- and post-survey, after normalization to account for the differing number of participants that completed the surveys. It can be seen from Figure 13 that all of the students either agree or strongly agree that energy and engineering are interesting, but we saw a significant downturn in the number of strongly agree responses. This indicates that the students were not particularly interested in the Energy Week activities and we may need to revisit the activities or how we present them so as to increase interest and enthusiasm.

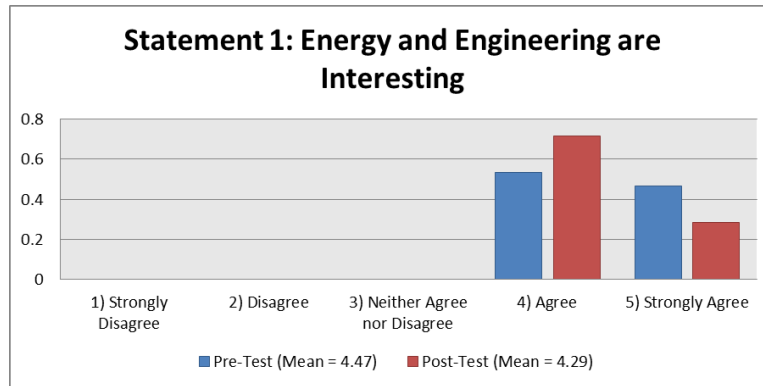


Figure 13: High School Students' Interest in Energy and Engineering

The post-survey results in Figure 14 show a minor shift toward Strongly Agree, but also show an increase in Disagree where there were zero responses in this category in the pre-survey. It is hard to draw a conclusion from the results shown in Figure 14; some students found the activities and presentations made them more excited and some became less excited after Energy Week.

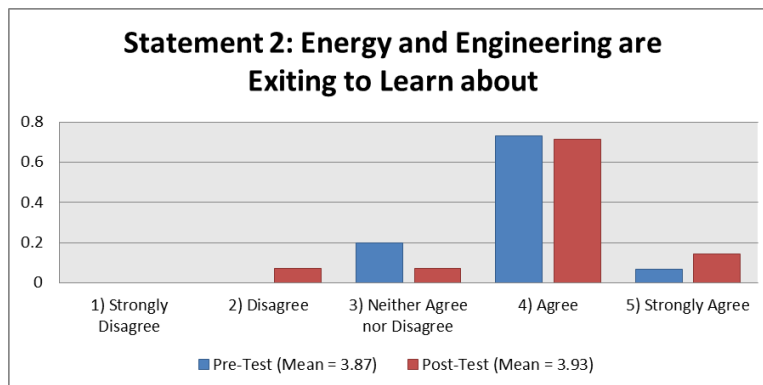


Figure 14: High School Students' Excitement to Learn about Energy and Engineering

Figure 15 shows an increase in how energy and engineering motivate the students to attend class. We can clearly see the increase in the mean and a significant increase in the Strongly Agree category. Given that the program schedule included no extracurricular activities outside of the energy activities, the results suggest that the materials learned through Energy Week increased the motivation of students to want to attend class and therefore it is plausible to say that the students had an increased interest in learning about energy and engineering as a result of Energy Week.

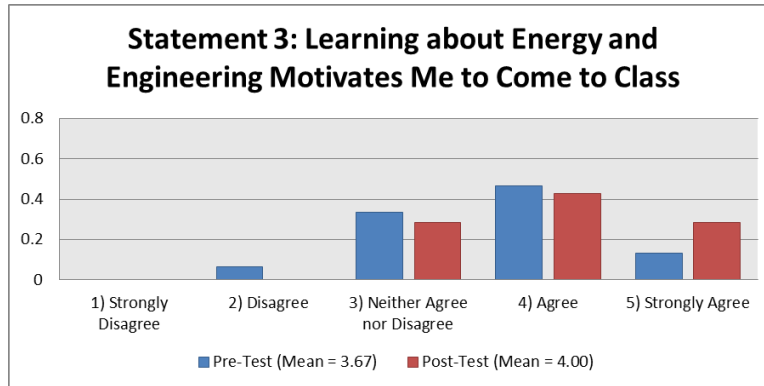


Figure 15: High School Students' Motivation to Attend Class because of Energy and Engineering

The students were asked how each activity affected their interest, motivation, excitement and knowledge based on the Likert scale outlined above. Descriptions for the four activities in this question are as follows:

- 1) **MDF Car Design Challenge:** The students were introduced to CAD drawing using SolidWorks. They were then instructed on how to draw simple parts which included disk shaped wheels and a rectangular shaped body. The students were given laser cut Medium-density Fiberboard (MDF) pieces that had the same dimensions as their CAD drawings. They were tasked with combining the pieces to make a simple vehicle, as can be seen in Figure 16. The goal was to win a downhill race, so the students had to consider drag and frictional losses, but there was also an award for most stylish car so the students could have some fun with creativity.



Figure 16: MDF Car Build and Race

- 2) **SolidWorks:** The students were instructed on how to draw simple parts and how to assemble relatively complex Lego assemblies in SolidWorks, as can be seen in Figure 17.

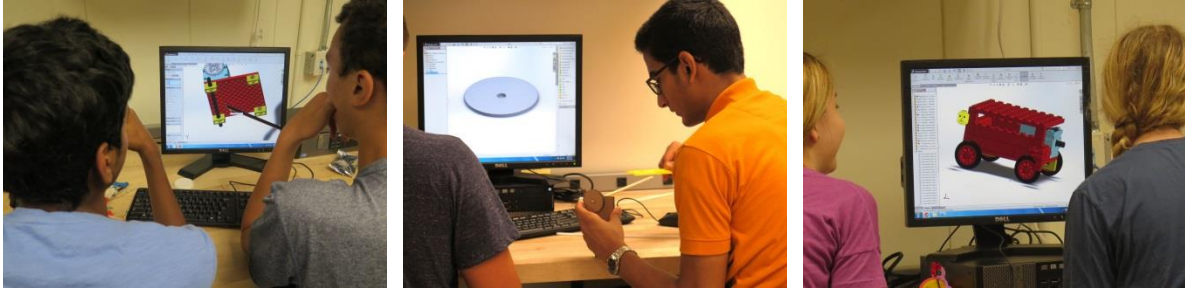


Figure 17: SolidWorks Parts and Assembly CAD Drawings

- 3) Solar Lego Car Design Challenge: The Students were given a solar panel, Lego motor and were allowed to use the huge assortment of Legos at Robert Morris University to build a solar powered Lego car. The cars were then brought outside to race using only the sunlight. This design challenge incorporated gear ratios, weight and structural integrity, along with estimation of the best angle to collect the most solar radiation. Images from the solar Lego challenge can be seen in Figure 18.



Figure 18: Solar Lego Car Design Challenge

- 4) Introduction to Arduinos: This portion of Energy Week was designed to introduce the students to control systems and automation, and specifically as they apply to energy. There was a lesson on energy controls and how that relates to a smart grid and power sensors. Figure 19 show images from the Arduino exercises.



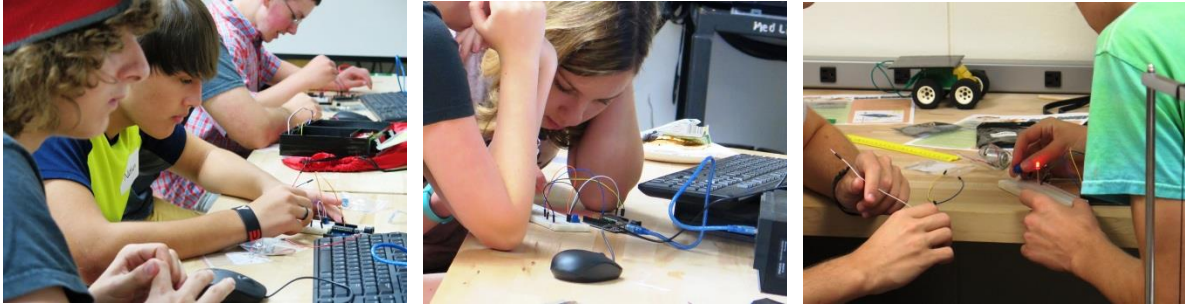


Figure 19: Introduction to Arduino and Control Systems

As can be seen in Figure 20, the solar Lego car design challenge received the highest scores in all four categories. This appeared to provide the most fun, interest, motivation, excitement and learning gains. The MDF car design had the second highest scores in all categories except for the learning gains category where the Arduino kits scored a bit higher. The racing of the cars and the associated competition between students was most likely the biggest driving forces in the high scores. The students also appeared to enjoy the design and fabrication process as well. The Arduino had fairly high scores too, while the SolidWorks category definitely scored the lowest. The students became frustrated with SolidWorks at times, as students often do when working with CAD software. A large part of this frustration was most likely in the Lego assembly, because the assembly was complex and caused the instructors to have a difficult time assisting the students. Organizers of future Energy Week events should reevaluate has this portion of the week is designed and instructed.

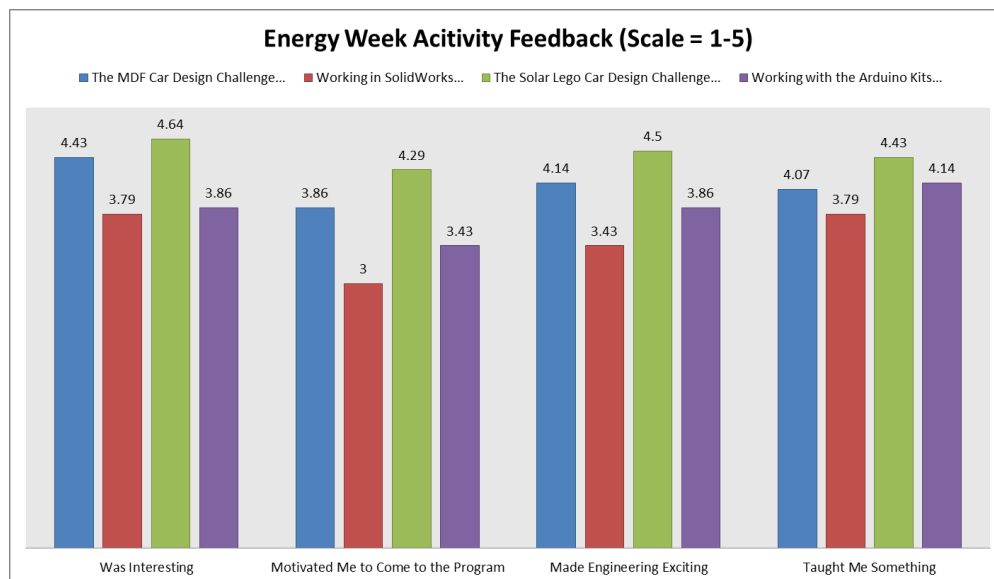


Figure 20: High School Student Activity Interest

The next six figures detail the results from the middle school participants pre- and post-surveys after normalization to account for the differing number of participants that completed the surveys. Overall, we can see much more positive gains in post-surveys for all of the categories.

It can be seen from Figure 21 that there was a significant increase in the strongly agree category and the majority of the results have shifted toward the right, implying that Energy Week increased interest in energy and engineering for the students. We can also see a significant increase in the mean from the pre-test value of 4.00 to the post-test value of 4.35.

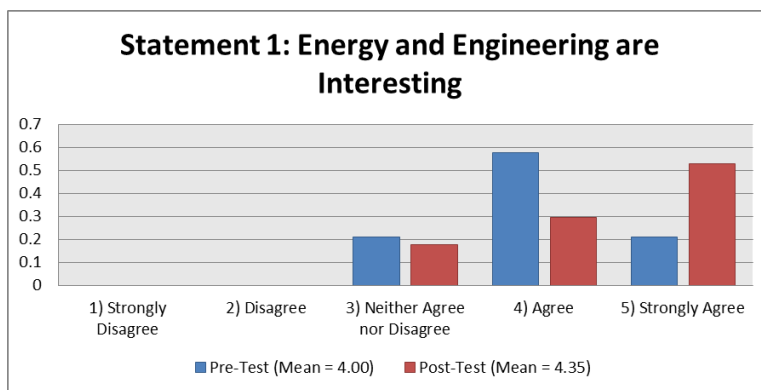


Figure 21: Middle School Students' Interest in Energy and Engineering

Figure 22 shows a similar trend to that of the high school students. We see an increase in the strongly agree category, but also see that a student responded disagree. This chart does not display a clear trend and it is worth noting that the pre- and post-survey mean is also very close.

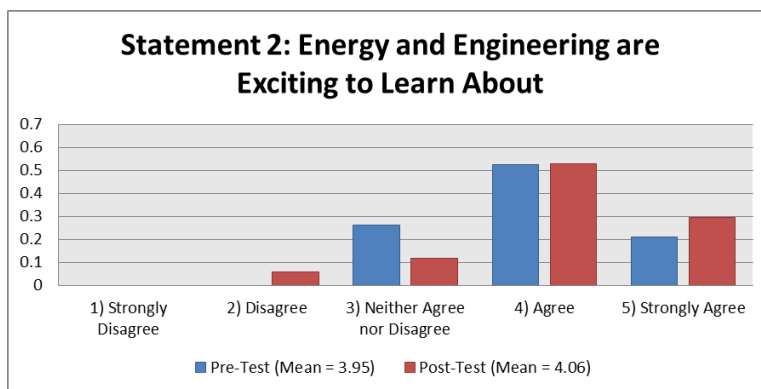


Figure 22: Middle School Students' Excitement to Learn about Energy and Engineering

A significant trend toward the right can be seen in Figure 23, which implies that the middle school students may be more motivated to attend classes related to energy and engineering after participating in Energy Week.



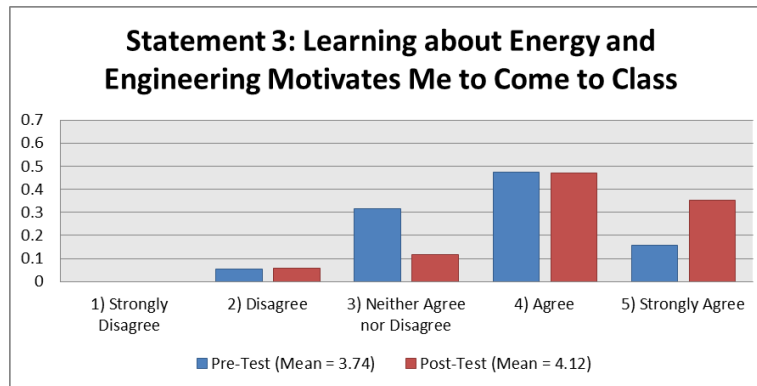


Figure 23: Middle School Students' Motivation to Attend Class because of Energy and Engineering

The following three survey question results were focused on teamwork, and perceived success of the team. Of all the results from the Energy Week survey, the largest gains from the pre- to post-survey can be found regarding the enjoyment of working in a team. This may be due to all of the Energy Week activities being geared toward group work, or it may simply be due to the fact that the students became more comfortable with one another as the event went on.

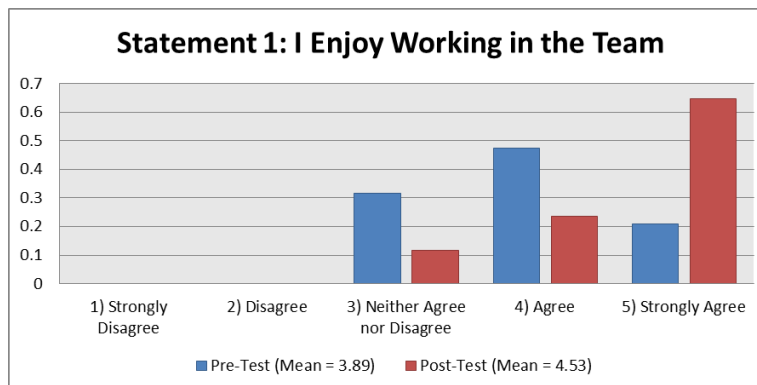


Figure 24: Middle School Students' Enjoyment in Teamwork

Figure 25 also shows promising gains in the confidence of the student regarding his/her contributions to the team in taking on a design challenge. A component of the gains are most likely related to the students comfort in expressing ideas to the group as the student became more comfortable interacting with his/her teammates.

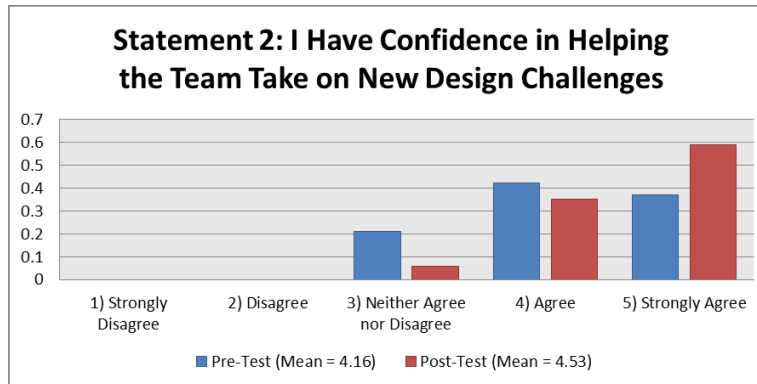


Figure 25: Middle School Students' Confidence to Contribute to the Team

The final survey question dealt with how much the student perceived their contribution to the team. This question also had gains from the pre- to post-survey, although not as drastic as the results from the other teamwork questions. This question not only assesses the students' perception of their own self-worth to the group, but there also has to be an inherent belief that the group was successful in their task. That inherent component may have brought reduced the post-survey score because a student may not strongly agree if their team was unsuccessful, no matter how much the contribution level was.

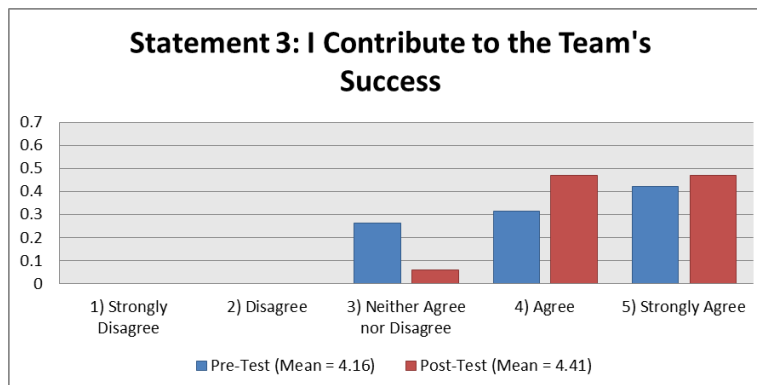


Figure 26: Middle School Students' Perception on How Much They Contribute to the Team

## Conclusion

Results from the ongoing study demonstrate that hands-on tiered challenges have a positive impact on the student experience with respect to their interests, attitudes and, motivation. The challenges worked well for the middle school and high-school age groups and the benefits are multi-faceted. We found that the programs were valuable in increasing their interest and attitudes towards energy, engineering and sustainability but that refinement is necessary for the more open-ended concepts and design challenges that engage the higher cognitive levels of Bloom's Taxonomy. The responses for "learning perceptions" corresponded well with the rest of the affective assessment and demonstrated the use of tiered energy challenges as a way to simultaneously increase engagement for three separate but related topics; energy, engineering

and sustainability. In future Energy Week events, we will have to evaluate ways to make the week more engaging and determine ways to improve upon the last event. As can be seen in the results shown in Figure 20, the SolidWorks activities had the lowest student activity interest scores and therefore would be a great place to start evaluating for improvements. One possibility would be to redesign this module by simplifying the SolidWorks Lego assembly and guiding the students through a more well-defined exercise instead of allowing them to simply design any Lego vehicle that they want. This would give students more direction and better explain the assembly functions in SolidWorks.

## Appendix A

The following question was administered weekly to gauge students' learning perception.

After this week, I feel that I have learned more about....					
	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Sustainability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Energy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Engineering	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The Engineering Design Process	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
What Engineers Do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

The following question was administered in the pre-survey to serve as a baseline for the students' interest.

What would you like to learn more about?

- ☐ Engineering
- ☐ Energy
- ☐ Sustainability
- ☐ Computer Coding
- ☐ Simple Machines
- ☐ Computer Aided Design (CAD)

The next question was administered weekly to gauge how each week contributed to the students' interest. The results are compared to the above question about interests to measure the interest gains.

After this week, I am more interested in...	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Sustainability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Energy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Engineering	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The Engineering Design Process	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
What Engineers Do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

The following questions are an example of a question that was asked about each design challenge that the students conducted throughout the program. This question was asked at the end of the week in which they participated in the design project. The responses were used to gauge motivation, enthusiasm and engagement.

The car design challenge....					
	Strongly disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Was interesting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Motivated me to come to class	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Made engineering exciting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Taught me something	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

The following question is one of the self-efficacy questions that were asked in the pre-survey. The same exact questions will be asked in the post-survey to measure the gains.

[illegible]

## References

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