Evaluation of Adoptability: The Iterative Development of an Energy Production Device for the Middle School Classroom

by
Sam Heck

A PROJECT

submitted to

Oregon State University

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in partial fulfillment of
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degree of

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(Honors Scholar)

Presented May 29, 2015
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AN ABSTRACT OF THE THESIS OF

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Abstract approved: ____

Shane Brown

This study conducts follow up research to my Mechanical Engineering Senior Project that was completed in March 2015. It follows the Student Powered Hydro and Entertainment Device (SPHED) as it is used in various middle school and high school classrooms. SPHED has three modules: a power generation module, a hydropower module and an entertainment module. The user spins a large acrylic disk on the power generation module to create electricity that can be used by the other two modules. The hydropower module uses this electricity to displace water to a higher potential energy before using the water to power a small water wheel. The entertainment module uses the electricity to power a television that is used for students to play a variation of Pac Man. Rather than a joystick, students are required to work together using four buttons: up, down, left, and right. If the disk stops spinning the TV turns off. My Honors Thesis is an attempt to understand the strengths and weaknesses of SPHED, as well as offer advice to future Mechanical Senior Projects teams. Specifically, this thesis asks how adoptable SPHED is within the standard classroom. Through research, characteristics of adoptable products were determined and with these traits, interview questions were constructed. The questions target key aspects of the device linked to these characteristics and encourages participants to highlight them specifically. Interviews were then conducted with teachers who have directly used the device with their students. While the results were positive, there were a few areas that could improve to create a more adoptable device. Many teachers were concerned with durability and lack of instruction and others felt as thought the entertainment module didn't hold a lot of educational value. Even with these concerns the overall conclusion is the SPHED is an extremely adoptable product.

Key Words:

- Module
- Mechanical Engineering
- Hydropower
- Adopt
- SMILE (Science and Math Investigative Learning Experiences)
- SPHED (Student Powered Hydro and Entertainment Device)

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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Sam Heck, Author

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1 Introduction

When designing a product to be used by the public, there is one characteristic above all that is important. The product must be desirable enough so that consumers voluntarily choose to obtain it; it must be adoptable. I recently completed my Mechanical Engineering Senior Project where my team and I built a product for middle and high school teachers. This thesis discusses my Senior Project and the process of creating an adoptable product as well as the follow up research I conducted to determine whether it was adoptable within the classroom.

1.1 Project Sponsor Program

The Senior Project was a team effort conducted by two fellow classmates and myself. All three of us are graduating Mechanical Engineers and have lived together for a number of years. Not only did our prior relationship help with regards to scheduling and dividing the work, it made for a really comfortable, more relaxed environment in which ideas could be easily discussed. This increased efficiency within the team ultimately gave the ability to create a concrete design and a high quality final product despite the compressed timeline.

This project worked with Science and Math Investigative Learning Experiences (SMILE), a program designed to "increase the number of minority, low income, historically underrepresented, and other educationally underserved students who graduate from high school, qualified to go onto college, and pursue careers in science, math, engineering, health care, and teaching" [1]. Over 7,500 students have been involved in SMILE in the past 25 years. SMILE employees visit rural schools across Oregon (Figure 1) hosting after school clubs and camps as well as holding events on OSU campus [2].

While SMILE is an Oregon based program designed to increase interest in STEM (Science, Technology, Engineering and Mathematics) education, the lack of engineering education at younger ages is a concern nationwide. An article in The Journal of Technology Studies states that, "Technological fields, like engineering, are in desperate need of more qualified workers, yet not enough students are pursuing studies in science, technology, engineering, or mathematics (STEM) that would prepare them for technical careers." [3] The article continues on to discuss both the importance of engineering specifically, as well as how it can be effectively taught to younger ages. It states that "The use of practical, hands-on applications of mathematical and scientific concepts across various engineering topics will help students to link scientific concepts with technology, problem solving, and design, and to apply their classroom lessons to real-life problems." [3]

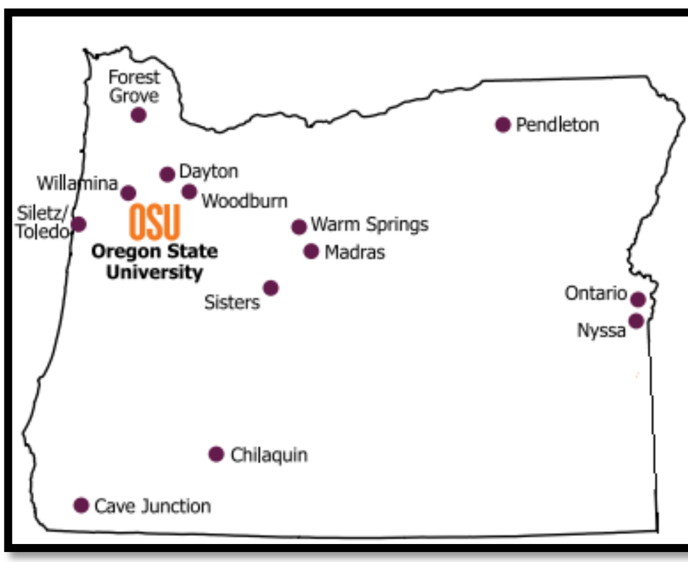

Figure 1: SMILE communities within Oregon

According to the President's Council of Advisors on Science and Technology (PCAST), "less than one-third of U.S. eighth graders show proficiency in mathematics and science." [4] Furthermore, "African Americans, Hispanics, Native Americans, and women are seriously underrepresented in many STEM fields." [4] It is the combinations of these concerns and thought processes that inspired this work.

1.2 Project Description and Unique Challenges

The task was to build a portable device designed to teach fundamental concepts of energy, basic mechanical engineering, and electrical principles. Some specific learning outcomes of the system included: power consumption, energy efficiency, sustainability, and a connection to real world energy use. The machine needed to engage students both physically and mentally, with a goal of introducing engineering and inspiring the students. The budget for the project was $1000. The full project statement can be found in Appendix A.

Additionally, videos were created for the students showing the design process from initial concept through production and they were uploaded to youtube.com on the channel, "SMILE Program." These videos allow the teachers to follow along with the engineering process from design through construction. The goal of the videos was to introduce students to the engineering aspect involved with the project. There are three videos each roughly five minutes long. The first video follows the brainstorming and modeling process; the second video covers the physical construction and tools used, and the third video demonstrates the finished device. While the device itself was used at a handful of schools throughout Oregon, the videos are widely available not only to teachers involved with SMILE, but to anyone with any interest in the subject material. This makes them incredibly important and a valuable resource exceeding the expected life of the device. These are all reasons why the videos are so important and could even be considered the most important aspect of the project.

While this Senior Project was a requirement for a college class, it was a unique challenge for a number of reasons. First, the new target audience of middle school students was unlike any project I had experienced. The majority of assignments throughout college are read and graded by individuals that are already familiar with the subject material. This project, however, required creating something that taught concepts to students for the first time. Second, the relatively broad and open-ended instructions allowed for a lot of creativity. Third, the team was able to work directly with the customer; it was a unique experience without a right or wrong answer. There were weekly meetings with the sponsor from the SMILE program and the team received feedback and voiced concerns directly to the end user. Lastly, despite the team consisting of three mechanical engineers, the project was largely electrical engineering. The team was forced to learn information quickly and be able to correctly apply it to the device, which ended up being one of the most difficult challenges.

2 Design Solution

This section details the process of developing a solution from the initial project requirements presented in section 1. This process involves identifying customers and their requirements, conducting background research and generating solutions.

2.1 Customer Requirements

With the goal of the project clearly defined, it was time to come up with how to accomplish it. The first step was to identify customers and create a list of requirements. These requirements would be used to optimize the device for a specific customer with the goal of increasing its adoptability. While the main customer would be the students that eventually used the device, it was important to remember the teachers that would be supplementing this into their lesson plans, and the SMILE

sponsor that would travel across Oregon with the device. Furthermore, the videos needed to be as in depth and educational as possible, while still remaining engaging for the students.
The requirements had to be specific for each customer in order to maximize adoptability. For the students, it was important that the device was fun and engaging; something that they would want to use. Additionally, there had to be some level of entertainment value for students that were watching, seeing as not all students would likely be participating at the same time. Some specific requirements for the students included: engages user, excites spectators, and engages spectators.

Requirements for the teachers were mostly learning based and focused heavily on learning concepts and educational value. The teachers would be in charge of setting up the device and facilitating. Some specific requirements for the teachers included: teaches multiple learning outcomes, short setup time, demonstrates power and energy concepts, and child-appropriate.

For the project sponsor, the device had to be portable and durable. Traveling through rural Oregon meant that it needed to be able to withstand vibration while fitting in the back of a Subaru Outback. Additionally, the project sponsor paid for the device. This meant that the cheaper it was, the more adoptable it would be for the sponsor. Specific customer requirements for the project sponsor included: light weight, small size, durable, and reasonable cost.

The requirements for the videos were very similar to those of the students and the teachers. They needed to engage and entertain the students, while also having enough educational value that the teachers want to use them. They also needed to be simple enough that the students could clearly understand them. As mentioned in Section 1, the videos allowed for a more detailed look at the engineering aspect behind the device. They covered entirely different learning concepts that are equally as important. They needed to be professional quality and deliver a lot of information in a small amount of time. Some of the requirements for the videos included: high quality sound, efficient—information packed, excited viewer/engages viewer, and explained jargon. For the full list of customer requirements, see Appendix B.

2.2 Background Research and Brainstorming

Before the brainstorming process could begin it was important to understand the challenges associated with building this type of device. It is one thing to come up with great ideas, but it is an entirely different challenge to effectively construct it and have it be operational. The team's first course of action was background research, and which began at the Oregon Museum of Science and Industry (OMSI). This museum is highly catered to children and created hundreds of exhibits that demonstrate different educational concepts through direct hands on interaction. It was important for the team to design an adoptable device and the employees at OMSI were an excellent resource for achieving this goal. A meeting was scheduled with the manager of exhibit production and the team toured the warehouse where the exhibits are constructed. He was able to point out patterns between the devices they have built and gave advise on how to construct these systems. From this evaluation, four major design ideas were documented:

- **Using “Try this:” signs**. These signs are a call to action to a user that might otherwise not understand how the device works. They simply help engage the user with the device correctly. Figure 2 shows an example of a “Try this:” sign.
- **Using engineering plastics**. Engineering plastics such as acetyl, acrylic, and polycarbonate should be used because they are durable, easy to machine, and look professional.
- **Visually exposing the inner-workings of devices**. This allows the user to see and understand how the device works. Almost every device at OMSI has the ability to see the inner-workings. Figure 3 shows an example of engineering plastic being used that shows the inner mechanics of the device.
- **Making user inputs “foolproof”**. Students are less likely to carefully read instructions before using the device. It is essential that the device can be used incorrectly without damage. For example, a crank that spins in one direction needs to be able to spin in the other direction without breaking or damaging the machine.

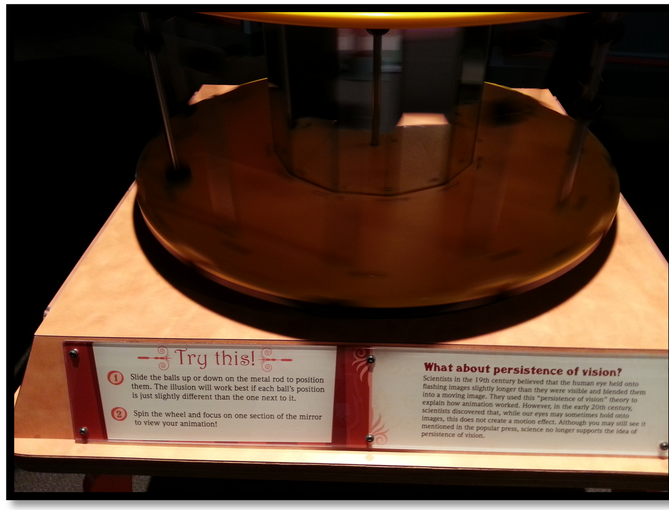

Figure 2: Example of “Try this” sign at OMSI

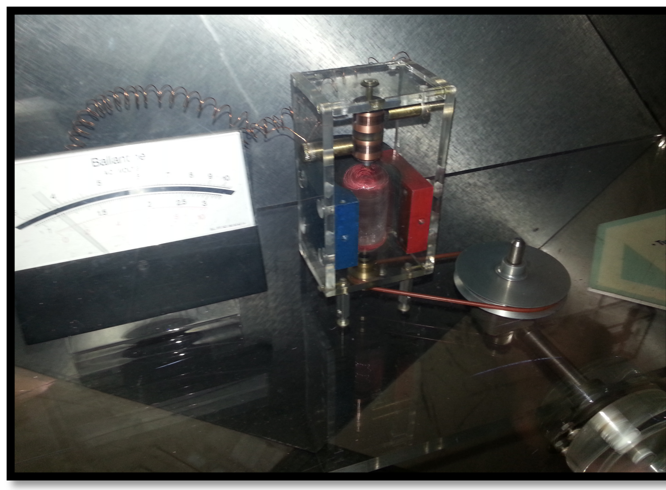

Figure 3: Example of clear plastic being used at OMSI

2.3 Design Solution

With background research complete and good comprehension of the scope of this project, a design needed to be finalized. The design chosen was modular and contained three different components: the power generation module, the hydropower module, and the entertainment module. The device was named SPHED (Student Powered Hydro and Entertainment Device).

The first component is the power generation module (Figure 4). This module is the crux of the system, which supplies power to the other modules. The user generates power by spinning a large acrylic disk in a circle, which spins a large motor in reverse generating power that can be used. This module is roughly 18” wide by 18” long by 12” tall and has a high friction bottom allowing it to remain in place on the table while in use. The use of acrylic allows for the user to see within the device to observe both the motor and a wattmeter that displays the power and voltage being produced. This module is fully sealed, maintaining a safe barrier between the user and any moving parts and electrical wires. The goal of this module is to relate the physical process of cranking the wheel to both a numerical value of power and voltage provided by the wattmeter and the resulting use of the electricity.

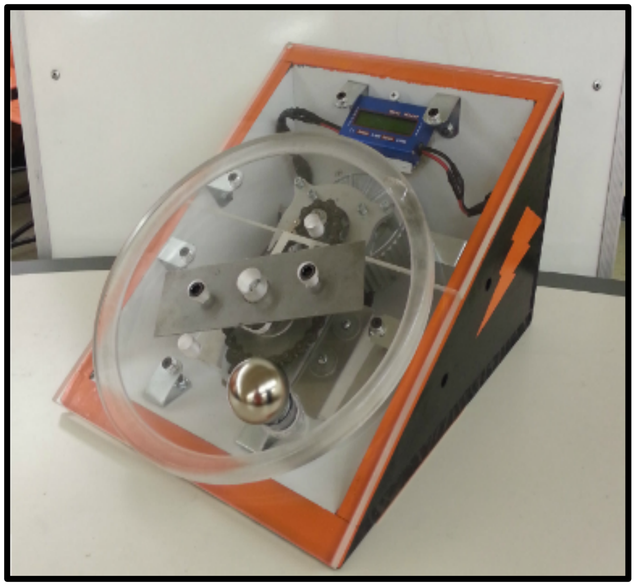

Figure 4: Power generation module

The second module is the hydropower module (Figure 5). This module uses the electricity generated from the power generation module to pump water from a low reservoir to a high reservoir. The high reservoir is then drained through a valve onto a water wheel, which in turn generates enough power to light a small LED light bulb. The entire module is made of acrylic allowing viewers to see what is happening from every angle and its “ant farm” shape minimizes the amount of water while maintaining the modules effectiveness. It is roughly 24” wide by 5” long by 24” tall. The device is properly sealed allowing no water to leak and all moving parts and electrical connections are safely located within the device. There are two legs that extend from the bottom of the module preventing it from tipping over. There are a number of learning concepts associated with this module including power losses due to efficiency, power storage through potential energy, general workings of a dam/ water turbine, and more.

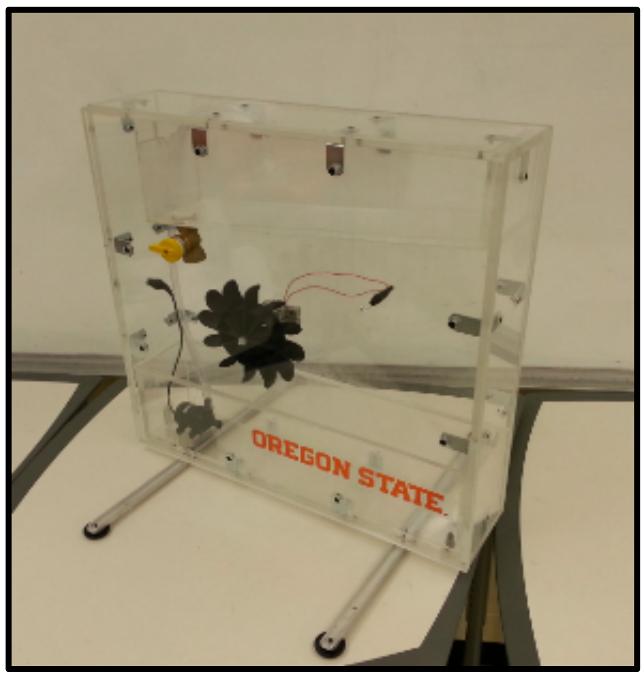

Figure 5: Hydropower module

The third and final module is the entertainment module (Figure 6). This module uses the generated electricity to power a small television. While the TV is on, students then use individual buttons to play Pac Man controlling his movements: up, down, right, and left. If the student powering the TV stops cranking the power generation module, the TV shuts off. The module is made mostly of wood with an acrylic panel covering the TV for additional screen protection. It is roughly 24” wide by 4” long by 16” tall. The device is completely sealed with all moving parts and electrical connections safely located within the device. There are two legs extending from the bottom of the module preventing it from tipping over. Learning concepts for this device include the direct correlation between cranking the wheel and electricity generated, and the teamwork required for four students to play Pac Man.

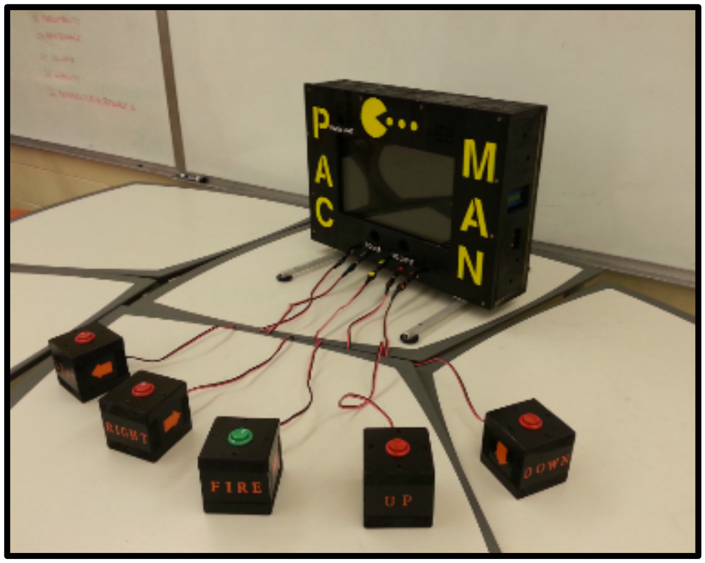

Figure 6: Entertainment module

Each of the three modules was put together to be as adoptable as possible. They were made to look professional and aesthetically pleasing. A lot of thought went into using big colorful letters, Oregon State decals, painted lightning bolts, arcade style buttons, and much more to ensure SPHED was desirable to all customers.

Throughout the construction process, the team also created the videos. The videos followed the process and highlighted key engineering aspects. The videos altered between a [1]Prezi presentation (Figure 7) and the face time with the team (Figure 8). All the videos introduced key vocab in a simple manner that could be easily understood by the students.

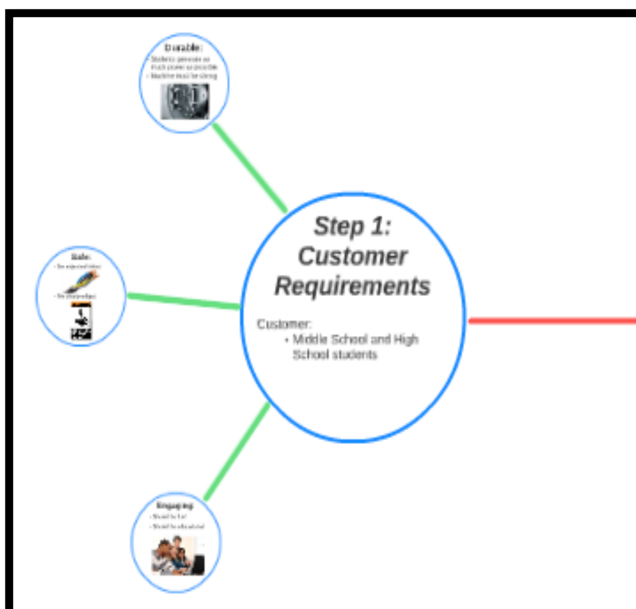

Figure 7: Prezi Presentation from Video #1

The first video follows the brainstorming and modeling process and the development of customer requirements. It specifically highlights a few of the more important requirements before showing the process of using a house of quality. It then gives an explanation of modeling and how it is used when engineering a product before showing SolidWorks models of our

[1] Prezi is a presentation tool that can be used as an alternative to traditional slide making programs such as PowerPoint. Instead of slides, Prezi makes use of one large canvas that allows you to pan and zoom to various parts of the canvas and emphasize the ideas presented there.

design. This is the first introduction to the modular design we chose. The purpose of this video is to teach the students about the preliminary work that is required with an engineering project.

Figure 8: Team Having Face Time with the Camera

The second video covered the physical construction and tools used. At this point SPHED was not complete, but the majority of construction had been finished. This video showed time-lapse production as well as introducing key machines the team used including a mill and a table saw. It discussed challenges the team had to overcome and showed SPHED at its current state. The purpose of this video was to show the actual building process and construction using real engineering.

The third video is a demonstration of the finished device as well as some examples of tests we ran to ensure its completion. At this point SPHED was completely finished. The video demonstrated each module working together with specific instructions. This video showed both a force test and a sharpness test to demonstrate its safety and durability. The purpose of this video was to show the final product that had been built as well as a simple set of instructions for teachers that might see the device in the future. Additionally it showed the testing process to ensure a product is fully complete.

3 Adoptability Research

This section begins the follow up research conducted to determine whether the device was actually adoptable. It covers the process of defining the term *adoptable* and developing intelligent interview questions.

3.1 Developing the Research Question

With SPHED designed and constructed, it was time to hand it off to the project sponsor. He would then travel across Oregon and use it with teachers and their students. In the past, this has been the end of the Senior Project team's involvement with the device. This year, however, I decided to travel with the sponsor and see how well SPHED works for the teachers. While there are many ways to determine whether the device is acceptable, the main question that I asked is how adoptable is the device within the classroom?

Before determining how adoptable SPHED is, the term itself must be defined. This, however, isn't just a simple definition. There are multiple characteristics in a product that makes it adoptable, each one as important as the next. *Diffusions of Innovations* by Everett Rogers [5] describes five characteristics that determine how adoptable a product is.

1. **Relative advantage:** How much better is it than what was used before? The greater the relative advantage, the greater rate the product will be adopted.

2. **Compatibility with existing values and practices:** How well does the product fit in with traditional methods? The less compatible an innovation is with its surrounding, the slower it will be adopted.
3. **Simplicity and ease of use**: How difficult is it to understand and use the product? The more effort needed to understand a product the slower the rate of adoption.
4. **Trialability**: How easily can the user experiment with the product? The user needs to be able to determine whether the product is a good fit before they commit. An adoptable product with high triability makes this an easy process.
5. **Observable results**: Can I see clear positive results from using this product? The easier it is for the user to see results the more adoptable a product will be.

3.2 Interview Questions

The next step was conducting interviews with the teachers that had used SPHED with their students. The interview questions had to specifically target the five characteristics and allow the teachers to provide constructive criticism. On the other hand, the questions had to be broad enough to allow participants to expand their answers in directions unforeseen. Many of the questions were designed with the help of an article from *The Qualitative Report* called "Qualitative Interview Design: A Practical Guide for Novice Investigators" [6]. Below is a list of the questions that were used and what characteristic they were designed to target.

1. How did it go?

Relative Advantage:

2. Do you believe this system helped teach the students?
   - How did it compare to a standard lesson?
   - Increased or decreased efficiency?

Compatibility with existing views and practices:

3. How easily do you think you could use this system in your classroom?
   - Set up/ take down?
   - Effective teaching?

Simplicity and ease of use:

4. Did anything go wrong?
   - Mechanical/electrical problems?
   - Effectively teaching a lesson?
5. Do you have any concerns for the future?
   - Mechanical/electrical problems?
   - Effectively teaching a lesson?
6. What level of facilitation was required with the students?
   - For them to use it correctly?
   - For them to learn the concepts?
   - Too much/ not enough?

Trialability:

7. If you received this system with no instructions, do you believe you could use it beneficially with your students?
   - Is it intuitive?
8. Were you able to assess whether it would be beneficial for your students?
   - How long did you need/ would you need in the future?

9. What red flags did you look for/ would look for in this sort of classroom device?

Observable Results:

10. What did you like the most?
    - Entertainment vs. education?
    - Specifically?
11. What did you think your students liked the most?
    - Entertainment vs. education?
    - Specifically?
12. What changes would you like to see for the system?

4 Results

This section highlights the results of the interviews with regards to the five characteristics introduced in section 3. It also discusses common trends that arose in the interviews that weren't specifically targeted by any individual question.

4.1 Interview Results by Characteristic

The results of the interviews were extremely positive; the teachers unanimously loved SPHED. That's not to say, however, that there weren't areas for improvement. While each characteristic was met to a certain degree, there were concerns among the teachers for a number of reasons. Below is an analysis of each characteristic based on the responses from the participants as well as some important topics that were repeatedly brought up. For a full list of the questions and answers given, see Appendix C.

Relative advantage:

Many of the answers received to this set of questions were more broadly referring to this type of device rather than SPHED itself. Many of the teachers praised the hands-on aspect involved with in class activities and acknowledged that there is definitely a benefit to getting students out of their seats. While it clearly could not replace previous lesson plans, there is obvious value in direct interaction with a learning device and for some students it is a much more effective tool than simply crunching numbers or reading the information from a book. One trend that was specific to SPHED as opposed to other similar devices was the ability to see within the machine. While other in class activities might show the same concepts, the clear plastic allows students to really understand how it works. There were no negative responses for this characteristic.

Compatibility with existing views and practices:

This set of questions was more difficult mainly because many of the teachers were not science teachers. This made it challenging to compare SPHED to instruments they had previously used in class. With this aside, it became very clear at this point that the age group of students had a large impact on the response of the teachers. Some elementary school teachers were concerned that it might lead to disciplinary issues among students, while it was not a concern of teachers of middle and high school students. As far as being able to incorporate it into a specific lesson plan, many of the teachers expressed concerns with their strict curriculums and compressed timelines. In other words, teachers are required to teach very specific material and there is not a lot of time to branch away and cover alternate topics. Set up and take down time was not an issue for any of the teachers although some were worried about the space required if SPHED were to be used long term. Overall the results were positive, but it was apparent that its use varied from teacher to teacher.

Simplicity and ease of use:
This category went very well with almost no complaints. Concerns with SPHED were small if any. Some teachers were concerned with the use of water and the fear of leaking was repeatedly expressed. Multiple teachers had concerns with the entertainment module and the fact that it might be too much fun, allowing students to glance over learning concepts and simply play the video game. There were no safety concerns. The amount of facilitation required varied depending on the age of the students. Younger students might need more guidance while older students could use it rather independently. The term "discovery learning" was used by multiple teachers to reference the benefits of less facilitation and allowing the students to figure it out on their own. The benefit here was that a student who discovers something without being told by a teacher is more likely to retain the knowledge. Other teachers seemed to think that while using SPHED was simple enough, in order for students to really capture the learning outcomes there would need to be some sort of facilitation. Introducing vocab and comparing the water wheel to a dam are examples of slight facilitation that could help a student grasp the learning concepts.

Trialability:
Trialability is a hard characteristic to analyze because it is usually done subconsciously. Teachers were required to think whether or not they had a firm grasp on SPHED after only an hour, but the result was a unanimous yes. When asked if the device would be beneficial without instructions, the answer was again yes and that the device is very intuitive. This said, however, almost every teacher would like to see some documentation, whether it explained set up and use or maybe just some examples of how SPHED could be used. Many teachers would like a list of the learning outcomes associated with the device so they could more accurately construct their lesson plans. As far as red flags associated with similar in class activities, almost every teacher said both durability and safety. Other teachers expressed concerns with the level of difficulty in understanding learning outcomes; some projects are simply too hard or too easy. This device in particular, however, seems to fall right in the middle.

Observable Results:
The observable results associated with SPHED was a fun topic because it really illustrated how it was helping the students. The most surprising benefit was the teamwork that it inspired. While Pac Man was designed to be played by four people at once, the difficulty and teamwork required was not anticipated. Even teachers who previously expressed concern about their students simply playing a video game were able to see the benefits of the communication and teamwork. Another popular topic was the easy correlation between physical work put into the device and the output of energy. The fact that as the student begins to spin the wheel the water is immediately pumped to the upper reservoir really reinforces this learning concept. Students were able to explain the process simply after using the machine with no guidance. Another surprising result was the ability of SPHED to engage all age groups. While the difference in age might alter how the device is used, it was apparent through use that this device can effectively engage and teach all ages. Elementary students might simply use the device and have fun with it while learning very basic concepts, while high school students could do efficiency calculations or any number of more advanced lessons. It was very clear in this section that the device had been a success and that it had accomplished all of its main goals.

4.2 Common Trends

While each characteristic is able to give clear insight as to whether or not SPHED is adoptable, it is important to look for trends outside of the questions. Throughout the interviews there were a few topics that arose that aren't specifically addressed in any one question.

The first topic was the use of models. When asked about future changes, numerous teachers suggested that rather than simply use SPHED, the students could build one of their own. The miniature versions would be on a smaller scale, but these teachers seemed to see a real benefit in allowing their students to actually design and build the system themselves. This is also beneficial because it falls under the Next Generation Science Standards (NGSS), a list of standards produced by the National Research Council designed to produce "college- and career-ready K–12" students [7]. Specifically, from a list of topics found in "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas" [8]. This is a list many teachers are required to target while others are simply encouraged.

A lot of the teachers wanted to see more engineering rather than just the mechanical and electrical concepts presented in SPHED. They were disappointed that it wasn't clearer just by using the device the amount of time and energy that had gone into building it. It was at this point that it became clear the teachers had neglected to watch the videos. Many of the teachers either didn't know what the videos were or had not been able to find the time to watch them with their students. This was extremely disappointing as the videos were a clear solution to the lack of engineering in the device. Teachers that requested more engineering within the device were directed to the videos.

Another topic that often arose was a discussion about the learning outcomes. Many of the teachers were very happy with this years learning outcomes because not only did it teach the students about electricity and power, but it was also very relatable to everyday life. The wattmeter on the power generation module was able to tell students exactly how much power they were generating. With this information it became clear just how much power goes into running a 60-watt light bulb or 2000-watt hair dryer. Teachers continually made comments about how this will help the students to not take these luxuries for granted and maybe even help them to live more proactive lifestyles.

Many of the teachers made positive comments regarding the hands-on aspect of SPHED. The ability to get students out of their seats and physically interact allows them to learn in their own way and relate more with the lesson. According to *Perspectives of Hands-On Science Teaching*, a book written by Program Director of the Nation Science Foundation David Haury, "Students in a hands-on science program will remember the material better, feel a sense of accomplishment when the task is completed, and be able to transfer that experience easier to other learning situations." [9]

5 Conclusion

This section takes the results determined in section 4 and uses them to look back at how SPHED could have been created with increased adoptability. It also includes advice that for next years SMILE Senior Project team, and special thanks for those who helped with both Senior Project and the Honors Thesis.

5.1 Hindsight

It is clear through the interview process that SPHED is a highly adoptable device. Every teacher stated that they would appreciate having SPHED in their classroom and that it does an excellent job at what it is designed to do. This being said, if I could go back and do it again there are a number of changes that I would make to the physical design as well as the research methods.

If I could go back to the design stage for Senior Project, I would probably think twice before using water. During the tour of OMSI, the team was warned about using water and it was suggested that the design be changed. The concerns were with sealing the device and avoiding damaging electrical connections. Although it turned out to be acceptable in the end, using water was no easy task. It required a lot of extra work and even then SPHED has minor issues with leaking.

Another design change that would have benefited the device would have been the elimination of a lot of the electrical engineering. The team was composed of three mechanical engineers and a huge portion of the entertainment module was electrical engineering. Rewiring Pac Man, installing voltage regulators and capacitors to allow the TV to work, and many more small electrical issues really held back the progress of the device as a whole. Efficiency would have drastically increased if a more mechanical design (like the hydro power module) had been chosen.

The last design change I might have implemented knowing what I know now would be an alternative method for power generation. Currently the power generation module operates at roughly 5% efficiency. This means that it requires a lot of excess work to generate just a small amount of electricity. This little amount of power is only barely enough to turn on the television and for a smaller student it can be nearly impossible. If I could alter the design I might explore a foot pedal method or simply a way to allow smaller students to generate more power. This could definitely improve the Pac Man experience and maybe help to stop the learning outcomes from being overshadowed by the entertainment value.

Diffusion of Innovations was an excellent resource that helped to guide my research. There were, however, some flaws in the way it was used. The term *diffusion* is defined as the spreading of something over time. In order to fully assess the adoptability of SPHED it would require a large amount of time. Due to a compressed time line, the research conducted for this thesis did not take the time to accurately measure the adoptability of SPHED. I was able to travel to one event where the device was used and from this had to infer the results of using it within the classroom. If I were to go back and redo my research, the number one change would be the amount of time. I would travel to schools and observe SPHED within an actual classroom being used as an actual lesson plan. I would interview many more teachers and refine my questions to get the best information possible.

Another research flaw that could be fixed with additional time would be the lack of exploration into the actual views and beliefs of the teachers. This would help in particular when analyzing the characteristic compatibility with existing views and practices. For my research I defined this as simply fitting in physically and asking teachers how they saw the device being used in their classrooms. If I could go back and have the time and resources, it would be very beneficial to additionally analyze the core beliefs and views of the teachers. Why did you become a teacher? What is your favorite part about teaching? Only when you truly know your customer in this sense can you determine whether a product is compatible with their existing views and practices and there fore, whether it is adoptable.

5.2 Advice For Future SMILE Senior Projects

The Senior Project was a great experience that allowed the team to engineer something to be proud of. It wasn't until traveling with the sponsor or completing this additional research, however, that it was truly clear exactly what had been built. Watching the kids interact and learn while using this device really highlighted the impact it would have, but more importantly it will help in the future to design a better, more adoptable product. Through this research, it was not only clear what was done right, but what could be improved upon. Below are some things done well, some suggestions for the device and advice for future SMILE Senior Project teams.

1. **Understand your customers:**
   When creating an adoptable product it is absolutely essential that you understand your customers. One reason why the product isn't as adoptable as it could be is that many teachers simply can't use it. Many teachers stated that their curriculums are too strict and can't allow alternate lesson plans that aren't specifically tailored to their teaching requirements. The design could have greatly benefited from direct teacher input stating exactly what they could use in the classroom.

2. **Engage the teachers early:**
   Along with understanding your customers, it is important that they are involved in the engineering process. The weekly meetings with the project sponsor are a great example, and they allowed the team to design exactly what he was looking for. The teachers, on the other hand were relatively uninvolved. Even when they were called upon to watch the videos, the majority of them didn't comply. Scheduling interviews was an extremely challenging process and it cost a large amount of time from an already compressed time line. I advise next years SMILE Senior Project team to develop relations early and get the teachers involved.

3. **Finish early:**
   Many teachers were concerned about the durability of SPHED. There was a slight leak in the corner, the screws weren't stainless steal and were beginning to rust, some of the paint was wearing off of the controllers, these are all examples of little problems that could have been fixed with an extra week. The end of almost any project will be stressful and rushed so it is very important to leave extra time to take care of the little things.

4. **Be wary of using water:**
   This is advice that OMSI gave from the very beginning. They warned that water is very hard to control and that the device might be better off if it was avoided. In the end it was effectively used, but it was no small task. Keeping the water from leaking or getting in the electrical connections was one of the largest challenges of the whole project, much harder than anticipated. For future SMILE teams, think twice before using water.

5. **Documentation:**
   This parallels finishing early, but it is important not to underestimate the power of documentation. The team planned on creating detailed instructions as well as lesson plans for the device for the teachers, but unfortunately ran out of time. When conducting the interviews, teachers expressed how helpful this would be. Trialability and therefore adoptability is greatly improved when the user has clear instructions.

6. **Safety and durability:**
   This is one area where SPHED greatly excelled, but at no small cost. When working with children it is imperative that a product is safe and durable. Almost every test ran was an attempt to ensure these two qualities and in the end it paid off. Throughout the interviews the device was praised time and time again for how safe it was. Durability was called into question a couple times, but overall the consensus was that it was strong and well built. Out of all the customer requirements, these two were by far the most important.

5.3 Special Thanks

I am very grateful for the having the opportunity to design and construct this device and the help that I received in conducting this additional research for my Honors Thesis. The following is a list of people I would like to recognize and thank for their hard work and contributions.

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Dr. Brown is an associate professor for civil and construction engineering at Oregon State University. He was my Honors Thesis advisor and helped me to conduct effective and meaningful interviews as well as complete the requirements for my Honors Degree from OSU.

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Peter and Ryan were my teammates throughout my Senior Project. Without them creating the device would not have been possible.

Jay Well:
Jay is the SMILE Programs Coordinator at Oregon State University and was the project sponsor for my Senior Project. He helped intensively with the design process as well as providing the budget.

Dr. Brady Gibbons:
Dr. Gibbons is an associate professor of mechanical engineering at Oregon State University and an associate head for MIME undergraduate programs. He was my faculty advisor for Senior Project and provided guidance through the design and construction process of the device.

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7 Appendix A: Original Project Description from Sponsor

Following is the original project description received from the sponsor:

The Science and Math Investigative Learning Experiences (SMILE) Program is a pre-college math and science enrichment program in rural areas throughout the state of Oregon aiming to build a vision for higher education for underrepresented youth. Approximately 650 SMILE students at the elementary, middle, and high school level attend weekly after school clubs where they engage in science and mathematics activities. The middle school (MS) and high school (HS) students have a specific focus on engineering design and modeling as well as computational and systems thinking. The Mechanical Engineering (ME) team will support this focus through the creation of their engineering and design project.

The ME team will be tasked with building a portable system that can be used by MS and HS students to learn about the fundamental concepts of energy, basic mechanical engineering and electrical principles. The system will need to have a variety of components that engage students both physically and mentally. The system should teach students concepts that will connect to real world issues around energy use and sustainability. The team will document their design and engineering process steps in written and video form so that students and teachers in the SMILE afterschool math and science clubs can follow along during the process. Additionally, the team working with the program faculty, will design activities to share with teachers to support MS and HS students developing core understanding of engineering concepts around the ME team’s project.

The educational goals for the ME team are to model fundamental concepts of energy, basic mechanical engineering and electrical principles as well as the Engineering and Design Process (EDP). The ME team is also expected to be role models in engineering for the students as they engage in their own engineering activities. The work that the ME team completes will strengthen the quality of our curriculum, making engineering real for MS and HS students and teachers.

General expectations for the project:

< *As a team, you will design and build an attractive, durable, reusable and portable system to teach the fundamental concepts of energy, basic mechanical engineering, and electrical principles.*

< *Create needed teaching materials that adequately explain the project and connect it to real world issues around energy use and sustainability.*

< *The team will record each portion of their design and build process using digital video and linked to a specific element of the EDP. These videos will be shared with the program leaders to use with their clubs.*

< *The purpose of the project is to have an initial working prototype, materials and associated videos completed in time for the Teacher's Workshop session January 30th 2015.*

< *During this 2-hour workshop the team will lead an Engineering and Design session for the teachers explaining your project and engaging the teachers in a couple of the prepared activities.*

< *The final products include: A series of videos to engage students in the EDP as well as introduce them to the ME team’s project.*

< *There will be set biweekly team meetings throughout the fall and winter term to check in on the progress of the project held at the SMILE office with Jay Well.*

< *This project will require initiative, creativity, and the ability to think outside the box. The team will be the experts in engineering design for this project.*

8 Appendix B: List of Customer Requirements

CR #	Customer Requirement	Weight (250 sum)	Comments
1	Durable	20	Must be durable enough for children's use
2	Safe	18	Must be safe to use for children
3	Small size	18	Must fit in a Subaru Outback
4	Engages user	18	Must be fun, interesting, feel like a game
5	Light weight	14	Must be carried in pieces by one person
6	Allows for multiple users at once	14	Must allow multiple users to keep multiple students interested constantly
7	Excites spectators	12	Must be also fun to watch and creates a desire to use
8	Teaches multiple learning outcomes	12	Must teach multiple lessons by using and reading signs
9	Short setup time	8	Must be set up within 30 minutes
10	Allows for any sized person	8	Middle School students vary a lot in size
11	Reasonable cost	8	Budget of $1000 or less
12	Well documented	5	We want the design well documented for long term use
13	Unique user experience	5	Each student must be able to have a slightly different experience each time
14	Easy to maintain/repair	5	Must be simple to repair or maintain so an engineer does not have to fix it
15	Easy to manufacture & assemble	5	Must be simple to manufacture and assemble for years down the road
16	Demonstrates power and energy concepts	LTE	Must teach children lessons specifically about power and energy
17	Demonstrates sustainability	LTE	Must teach children about energy sustainability
18	Child-appropriate	LTE	Must be simple enough and appropriate enough for middle school students
19	Display labels in Spanish & English	LTE	Must be labeled in both languages
20	Brief duration (each video about 5 minutes)	17	Must not be too long or will bore everyone
21	Efficient—information packed	16	With only five minutes, we need to pack a lot of information into five minutes
22	Excites viewer/engages viewer	13	Exciting for children especially
23	Refined (story-boarding ahead of time, etc.)	12	Have as little transition time possible

24	Professional video	8	Make sure everything is well scripted
25	High quality sound	7	Everything is clear
26	Explain jargon	7	Explain all technical words
27	Design process video	LTE	
28	Manufacturing process video	LTE	
29	Final product presentation video	LTE	

9 Appendix C: Interview responses by Question

1. How did it go?

Responses varied in detail, but were consistently positive. General trends in initial response include:

- **Very kid friendly/ students loved it**
- **Excellent portrayal of concepts**
- **Loved the hands on**

2. Do you believe this system helped teach the students?

Unanimous yes. General trends include:

- **Direct, hands on correlation and use of visuals increased rate of understanding**
- **Easier to relate to than numbers and calculations that might be seen in a standard lesson plan**
- **Appreciated being able to see inner workings**

3. How easily do you think you could use this system in your classroom?

Answers varied between teachers. Often depended on both subject the teacher taught and age group of students. General trends include:

- **Not easily, it's not my subject/ grade level curriculum**
- **Might have discipline issues with students too young (elementary)**
- **Would be hard to incorporate into my specific lesson plan (might have to tweak plan)**
- **Set up/ take down would not be a problem at all (unanimous)**
- **Long term setup → concern with space**
- **Would be a great tool to either teach concepts or further reinforce previously taught concepts**

4. Did anything go wrong?
   - **Almost unanimous nothing went wrong**
   - **Slight leaking in the corner**
   - **Need to start quickly to activate wattmeter (sometimes users are too shy)**

5. Do you have any concerns for the future?
   - **Tipping of water module (top heavy)**
   - **Leaking**
   - **Wants to ensure students learn and don't just have fun**
   - **Power module durability (takes a beating)**
   - **No safety concerns (unanimous)**

6. What level of facilitation was required with the students?

Answered ranged hugely. Some teachers said they would need to be right there others said it benefits students to learn alone. Largely due to age groups and teaching styles.

- **Cautious approach (rather safe than sorry)**
- **Leave students alone with it (discovery learning)**
- **Depends on the students**
- **Could be broken**
- **Students might be interested in taking it apart**
- **Students could figure it out on their own, but would need guidance to achieve learning concepts (vocab, etc.)**
- **No concern for safety (it's safe)**

- **Concerned students might just play Pac Man**

7. If you received this system with no instructions, do you believe you could use it beneficially with your students?

Most teachers would like ideas, but would probably branch off of them to cover more specifics. Intuitive correlates with age.

- **Could figure out how to use it, but a lesson plan might be helpful (give ideas for learning concepts)**
- **Very intuitive**
- **Don't need lesson plan, discovery learning**
- **Lesson plan would help for more in depth lessons for older students**

8. Were you able to assess whether it would be beneficial for your students?
   - Yes plenty of time and yes beneficial
   - Students loved it (high interest) → engaged learning

9. What red flags did you look for/ would look for in this sort of device?
   - **Is it safe?**
   - **Is it durable?**
   - **Is it too easy/ too complicated?**
   - **Setup/ tear down time**
   - **Controversial issues that lead to argument (competition, too many students, etc.)**

10. What did you like the most?
    - **Team work (almost unanimous)**
    - **Visualization and simplicity of mechanics (ability to see within)**
    - **Quick correlation (saw results immediately)**
    - **Concepts it portrays**
    - **Versatility between age groups**

11. What did you think your students liked the most?
    - **Depends on student**
    - **Pac Man/ video game (majority)**
    - **Direct correlation**
    - **Hands on**

12. What changes would you like to see for the system
    - **About half said "no change"**
    - **More ways to generate the power**
    - **Ability to create mini-models**
    - **More light bulbs = more energy**
    - **More written information**
    - **More clear numbers**
    - **Physically harder to play Pac Man (focus on learning rather than playing)**
    - **Ability for more students to participate at once**