Session #: ___________

MEASURING THE IMPACT OF ENGINEERING OUTREACH ON MIDDLE SCHOOL STUDENTS' PERCEPTIONS

Emily Dringenberg[1], Julia Wiener[2], Jennifer Groh[3] and Şenay Purzer[4]

[1] Purdue University, West Lafayette, Indiana; Email: edringen@purdue.edu
[2] Purdue University, West Lafayette, Indiana; Email: wiener@purdue.edu
[3] Purdue University, West Lafayette, Indiana; Email: jgroh@purdue.edu
[4] Purdue University, West Lafayette, Indiana; Email: spurzer@purdue.edu

1. ABSTRACT

Innovation to Reality (I2R) is a free, after-school engineering program launched in an effort to provide local 6^{th}-8^{th} grade students an opportunity to learn about engineering through college student leaders and hands-on activities. The purpose of this paper is to describe our evaluation of the current assessment being used to measure the impact of this program on middle school students' perceptions and understanding of engineering as well as participants' learning of content. The program evaluation model currently includes both qualitative and quantitative assessments such as: 1) pre- and post-surveys administered to participating students and 2) design artifacts created by the students. These instruments are used to help evaluate how well the mission of this program (which is to replace the often negative stereotype of an engineer with positive role models and improve students' perceptions of engineering and what engineers do) has been met and whether a socially relevant theme (e.g., addressing global water scarcity) enhances student knowledge of and interest in engineering and science. We aim to evaluate our current methods and then develop an improved assessment model. Once developed, this model will be disseminated for use with other pre-college, localized efforts of engineering outreach.

2. INTRODUCTION

Many local efforts to introduce students to engineering are made across the country. These programs commonly recognize the need to inspire youth to consider engineering as a rewarding career path and to replace the public's often incomplete understanding of what engineers do. Our program promotes these common themes via hands on engineering-related activities, and seeks to utilize undergraduate and graduate women in engineering as positive role models to replace often negative stereotypes of engineers. Our Women in Engineering Program (WIEP) has been leading various hands-on STEM activities for over 10 years serving students K-11. In addition, WIEP has over 15 years experience in student programming when considering its undergraduate and graduate mentoring programs.

The program of interest for this study, I2R, has been in action for three years serving middle school students from the surrounding area. For our various programming, we have historically measured our success by relying heavily on anecdotal evidence: informal surveys of participants, testimony of parents and volunteer/paid staff members. We are currently interested in developing an improved evaluation model to measure the impact of this program on middle school students' understanding of engineering concepts along with their perceptions of engineers and engineering as a potential career.

2.1 Research Purpose

The purpose of this paper is to discuss the initial phase of this development based on an analysis of our current assessment methods and information gathered from literature. The relevance of an appropriate evaluation model will allow us to prove what our program does for its participants and to provide us with better information for our funding agencies. Our funding has historically come from corporate or government sponsorship. To date, corporate sponsors have not required evaluations; simple demographics such as number of attendees have been considered sufficient. Government sponsorship requires a mid-year report with a very general request for project overview, progress, and expected outcome. However, the submission of the final report requires statistical and narrative information on the project, so the inclusion of a more formal quantitative and qualitative evaluation as we seek to develop will strengthen our report to any possible funding agencies. With the current push for effective K-12 engineering education, it is important to have a valid method for evaluating these types of programs that is easy to share and implement for other similar local efforts. We also recognize that success in evaluating one of our programs can be translated to any of WIEP's other outreach efforts.

2.2 Program Background

I2R is coordinated by WIEP and run by enthusiastic faculty, graduate, and undergraduate engineering students at Purdue University. For each I2R session, a Graduate Team (GT) comprised of STEM graduate students with the necessary expertise for each theme is assembled. These teams create and present the curriculum for the five weeks (once a week for two hours) with guidance and structural support from an I2R Coordinator (WIEP graduate student staff member), the WIEP Associate Director, and faculty mentors. Activities are selected from a wide range of resources that include STEM websites, STEM activities magazines, and Graduate Team expertise, and then are adapted for the specific session depending on the selected theme.

Faculty members are also invited as guest speaker or as leader of a laboratory tour. Undergraduate students in multiple engineering disciplines are hired to mentor small groups of I2R participants (4-5 students/group). In each session, 25-30 participants enrolled in I2R through a simple online registration process. Meetings are a mix of informational lectures, hands-on activities, and student projects. Meetings showcase different aspects of the selected topic and build upon each other from week to week. At the conclusion of our most recent session, which focused on global water shortage, student teams showcased poster presentations, which synthesized what they learned across all five meetings, and were asked to present a unique engineering solution to the global problem of water shortage to their parents and other invited guests.

3. LITERATURE REVIEW

In a recent study, Jeffers, Safferman and Safferman (2004) took a survey of the landscape of various K-12 outreach programs across the country. Their work found that primary reasons for investing in outreach include the following: increase engineering enrollment, diversify engineering, educate our future, teach the teacher, and develop undergraduate students (Jeffers *et al.*, 2004). Their summary of outreach programs revealed that many outreach efforts that occur on college campuses are camp-style programs for K-12 students, which may range from single day workshops to extended summer internship programs. Many other styles of outreach exist, and Jeffers, *et al.* (2004) provides the following common themes: active learning through hands-on activities, inquiry-based learning, curriculum supplements, engaged role models, younger student focus, and K-12 teacher involvement. With our middle school outreach, we are focused primarily on increasing engineering enrollment, diversifying engineering (with a focus on women), and developing female undergraduate engineering students.

A similar study, conducted by the Pre-Engineering Instructional and Outreach Program (PrE-IOP) at New Jersey Institute of Technology (NJIT), provided a comprehensive literature review and revealed findings similar to Jeffers and collegues. The PrE-IOP project was funded by a three-year High-Tech Workforce Excellence Grant from the New Jersey Commission on Higher Education (Rockland, Kimmel, & Bloom, 2002) and began as an effort to create an outreach program that would enable influential adults such as teachers, parents, or counselors to talk to students about engineering career paths and the potential benefits. To measure the benefits of their efforts, they first developed a survey to measure high school students' attitudes towards and knowledge about engineering (Rockland *et al.*, 2002). The following year, they administered their survey to high school students and their preliminary results suggested that while students may have positive impressions of engineering and are even considering engineering, they still know little about what engineers do and what types of careers are available within engineering (Hirsch, Gibbons, Kimmel, Rockland, & Bloom, 2003).

For example, the PrE-IOP program found during their development of an assessment for high school students that while 86% of the sample (n=381) responded that engineering would be an interesting career and 64% reported an interest in studying engineering in college, only 25% could accurately name five different types of engineers (Hirsch *et al.*, 2003). In addition, in a free response asking the students to list five types of engineers and an example of the type of work each discipline participates in, nearly half of the students gave two or fewer responses (Hirsch *et al.*, 2003). When the PrE-IOP program adapted their high school assessment for use with middle school students, they had similar findings. Although many of the students involved in their programming had positive attitudes towards STEM subjects, none of the students were able to give complete and accurate responses to the open ended question prompting for distinct disciplines of engineering and examples of related work (Gibbons, Hirsch, Kimmel, Rockland, Bloom, 2004). Gibbons *et al.* (2004) went on to call for more research to determine the perceptions that outside influences such as teachers, parents, and counselors hold of engineering and how those are (or are not) being communicated to students.

Another source we used to guide our search for relevant literature was a database of assessment protocols (https://engineering.purdue.edu/Inspire_center/assessment-center). This led us to a framework created by Assessing Women and Men in Engineering (AWE), which is in partnership with the Society of Women Engineers. This tool was quite thorough and considerable effort has been made to make it adaptable for easy use by others; it used a pre and post survey to collect data from middle school participants in engineering-related outreach. The assessment uses Likert scale type questions that address the following areas, which parallel our current project:

- Ratings for Hands-on Activities/Projects
- Ratings for Lecture-style Presentations
- Rating for Recruiting to a STEM Career and/or Institution
- Students' perception and familiarity with what engineers do
- Students' perception and interest in science and engineering (AWE, 2009)

This information from our review of both PrE-IOP and AWE resources will be used to inform the further development of our assessment instruments for our programming. However, we also found limited information on these instruments' validity and reliability.

4. RESEARCH QUESTIONS

The following research questions motivate the development of this evaluation model:

1) How well do I2R's current assessment instruments measure students' content knowledge?
2) How well do I2R's current assessment instruments measure students' perceptions of what engineers are and what engineers do and their interest in a career in science or engineering?

5. METHODS

5.1 Context of the Study

The I2R program is uniquely designed to provide middle school students with an engineering experience from Purdue's faculty, staff and current students, through a combination of hands-on engineering activities, faculty guest speakers, and laboratory tours as described previously in greater detail (Fitzpatrick, Groh, & Holloway, 2011). To date, themed sessions have been related to the science and engineering behind Biosensors, Alternative Energy, Diabetes, Water Scarcity, Climate Change and Food. Typically three of these themed sessions are offered during the academic year with each session meeting once per week for five weeks (two hours per meeting). These educational sessions take advantage of resources provided by faculty research across engineering and science departments and Purdue Research Centers.

5.2 Study Participants

The middle school students (6th-8th grade) that apply to the program come from the greater Lafayette area, and some of our outreach efforts have recruited students from as far away as Indianapolis. The number of applications received for the program has increased over the past years, with actual enrollment of around 90 students total in the current academic year (Table 1). We have observed increased diversification in terms of school, age and ethnicity of the applicants. Reasons for the increased application and diversification numbers may be attributed in part to the advertising efforts that included the following: e-mail to previous participants, postcard mail to University-generated mailing lists, e-mail to local public and private school corporations, e-mail to diverse associations (e.g. Girl Scouts, Big brother Big sister, Homeschool network, etc.) and more.

Table 1: Application to I2R Program – Totals by gender.

Year	Male	Female	Total
2011-2012	45	46	91

5.3 Data Sources

We collected data during an I2R outreach conducted in Fall 2011 during an I2R session with a Global Water Scarcity theme. Data sources included artifacts such as student worksheet responses, student posters, and a student and parent survey. These data were examined to gather information on our research questions of how well they assessed participants' content knowledge, perceptions of engineers/engineering, and interest in a career in engineering.

Worksheets: Throughout the sessions, students were given worksheets to supplement several of the different hands on activities and demonstrations that were developed and implemented as the I2R curriculum. The worksheets were used to both provide a method of organizing data being collected during the demonstration (e.g. students fill in a table with values as an activity is occurring) and to present students with questions both during and after the activity. To provide context for the data analysis, we will provide a brief explanation of the activities that required the worksheets that we analyzed.

- A hands-on demonstration of "the tragedy of the commons" was implemented during the water scarcity session of I2R. Students in small groups worked with one undergraduate helper to imagine that they are sharing access to a common water source, which was represented with a container holding 16 pieces of candy. Each student was to act as the head of their household, and was allowed to take as many pieces of candy (representing buckets of water) as they saw fit for their family. However, they were not able to see how much candy remained in the source. Taking only one "bucket" would result in death from dehydration. After each student took their share, the helper added enough pieces back to the source to double what was left. This continued around until the source was exhausted to demonstrate how many resources may be shared and common, but this can lead to exploitation. The students were then allowed during a second round to strategize how to repeat the activity and devising a way to reach sustainability within their community and limited "water" supply.

  The worksheet that supplemented this activity required students to record the amount of pieces taken by each group member and therefore keep track of how long their water supply lasted. Students were also expected to complete follow up questions on the worksheet, which included questions such as the following:
  1. What happened to the common resources (candy) in the 1st round?
  2. How long did it take to eliminate all your resources

3. Define carrying capacity
4. What happened to the common pond in part two? How was this different than part one?

- At another meeting of the same I2R session discussing global water scarcity, the students participated in an irrigation activity. This activity required the students to act as engineers who are faced with the task of transporting water to two different cities. Students were expected to transport two cups of water three feet into two separate cups evenly. They built their mechanism for transporting water from common household items such as straws, foil, rubber bands, tape, toothpicks, plastic piping, and popsicle sticks.

  The worksheet that was used to ask the students follow-up questions included the questions such as the following:
  1. Did you succeed in creating an irrigation system to split the two cups of water into two separate destination containers? What was your best result?
  2. If your system failed, what do you think went wrong
  3. Do you think that engineers have to adapt their original plans during the construction of systems or products? Why might they?
  4. If you were going to do this all over again, how would you change your design? Why?

Posters: Another data source was student posters. At the conclusion of the five weeks' of meetings, I2R participants are commonly asked to work in groups to create a poster presentation of their synthesis of what they have learned. These posters are displayed for parents at the final meeting for the session. Students are expected to display some of the content knowledge that they have gained as well as an original potential solution to the problem that is themed throughout the session.

Surveys: A final data source was in the form of pre and post student surveys and a parent survey. Since the origination of this program, these types of informal surveys have been used to gain insight into the effectiveness of the programming. They have focused on demographic questions, feedback on the student's enjoyment of different activities, and questions related to the students' ideas of what engineering is and their interest in engineering as a potential career. In years past, these surveys have remained as internal documents, but the current transition to framing this programming as a research project has caused us to want a standard measure of learning and perceptions for I2R. The current survey contains questions such as the following:
1. Do you want to go to college (Yes, No)
2. Did I2R change how you think about engineering? (Yes, No) Please explain (Open ended)
3. Which way did you learn the most? (Select from talks, demonstrations, hands-on activities)
4. Would you recommend I2R to a friend?

All three of these data sources were then submitted to basic data analysis.

5.4 Data Analysis

We reviewed the data that we collected from participants for content analysis. In other words, we searched the worksheets and submitted responses as well as the poster presentations for emerging patterns that could be considered evidence of student learning. This was in an effort to answer our first research question of how well our current evaluation models measure student content knowledge.

We also looked at the surveys that were administered in an effort to answer our second research question of how well those evaluation models measure students' perceptions of engineers/ engineering and their interest in pursuing a career in engineering. To begin to develop an improved survey, we coded the responses to open ended questions, which can then be used to frame our new questions. An example from the question "Tell us what you think engineering is" is as follows:

6. FINDINGS

Preliminary findings based on the first data set revealed to us that our current methods of evaluation are not very effective in aiding us in understanding how our programming is reaching its goal of replacing the often negative stereotype of an engineer with positive role models and improve students' perceptions of engineering and what engineers do while also enhancing student knowledge of and interest in engineering as a potential career path.

The investigation of our first research question (how well do I2R's current assessment instruments measure students' content knowledge?) brought us to the finding that the supplemental worksheets did little to evoke evidence of student learning of intended content. Many of the questions were procedural, which means that they asked about "what happened" during the activity and there was less focus on what the students understood conceptually about the application of what happened during the activity. By looking at the posters that students created, it was evident that a large majority of them were created by simply cutting and pasting the content that was provided to them in the sessions.

We now aim to develop rubrics that can be used to better assess students' posters for evidence of learning. For example, we could evaluate the final poster on the details of their selected design. In this case, an exemplary final poster presentation would include the following: a clear solution, a sketch with labels, clear application of content knowledge, use of technical vocabulary, and limitations of their design. It would also help data collection to add a handout that contains reflective questions to go with their final solution such as if they had more time, how would they work towards implementing their solution? Our findings related to our first research question confirm that we need to further develop our tools for assessing our outreach programming so that the student responses that we receive are able to be evaluated for evidence that students are learning content knowledge and how it relates to engineering. Table 2 shows an example of a rubric for this work-in-progress.

Table 2: Proposed Poster Rubric

	Exemplary/Good	**Needs Improvement**	**Needs Significant Improvement**
Details of Selected Design	There is a clear solution presented with enough detail, with a sketch and appropriate labels	The solution is presented with limited detail. Sketches are hard to interpret	There is no clear solution.
Application of Content Knowledge	The selected solution shows a clear application of content knowledge & is justified by sufficient evidence	The application of content knowledge is not explicit or not used to justify the design	The application of content knowledge is not evident
Scientific and Technical Vocabulary	Scientific and technical vocabulary and terms are used when necessary and appropriately	Some scientific and technical vocabulary and terms are used when necessary and appropriately	Scientific and technical vocabulary and terms are not used
Design Limitations	There is information on the limitations of the design	There is some information on the limitations of the design	There is no information on the limitations of the design

The investigation of our second research question (How well do I2R's current assessment instruments measure students' perceptions of what engineers are and what engineers do and their interest in a career in science or engineering?) also illustrated some ways that our current worksheets and surveys made it difficult to draw solid conclusions. Student responses on worksheets allowed for little analysis of whether the activities in which they participated truly shaped their understanding of what engineers do. The assessment we were using required students to summarize the activity that they did instead of the concepts that were explored or any ways in which the activity altered their perceptions. To improve our survey development, several trends were identified in the review of current assessment tools for K-12 engineering outreach. These decisions were informed by our analysis of open-ended questions in the survey such as "Tell us what you think engineering is" (See Table 3 for an example of coding). This analysis revealed seven themes in students' perceptions of engineering: improving life, making things, building things, working with machines, fixing things, designing, and inventing. This coding allowed us to develop our proposed questions for an improved survey, which can be found in the following section.

Table 3: Example of Analysis of Open-ended Survey Question.

Coded Theme	Student Response
How things work	Engineering is the study of how things work
Science, mechanics	Engineering is the science of mechanics
Fixing problems	Figuring out how to fix problems
Electronics (technology)	The study of electronics
Making things, technology	Using science and technology to make things
Work in a factory	Working in a factory
Creating, Machines	Creating and using machines
Building, improving life	the study and determination to build something that will make life easier
Inventing, improving life	inventing things for the better future
Building, making things	building stuff like shoes or buildings. Making chemicals, civil engineering, computer engineering
Design, improving life	I think engineering is where you build designs and make the world simpler and a better place.
Building	Building things
Building, inventing	The mechanics on working, building and inventing mechanisms
Building	building stuff
Building, improving life	Building things that will help people in the future and the present
Making, fixing	engineering is making or fixing
Technology	I think engineering is the study of improving technology
Improving life	I think engineering is when you do things that benefit people
Making things	Making things
Solve problems	Finding new ways to solve problems
Making things	People who make stuff
Making, solving problems	Thinking and making new ideas to solve problems
Machines	Making fixing machines
Design, improve life	An engineer is a person that designs new things to make life easier
Design, building	Designing and building stuff
Fixing	repairing stuff
Building	I think engineering is basically building something
Solving problems, inventing	thinking of ways to solve problems or invent new things
Machines	Working with machines

Questions, which are often formatted on a Likert scale and written in language appropriate for middle school students, can be administered before and after the programming to measure both students' perceptions of engineering/what engineers do as well as their interest in a career in the field of engineering. Some of the questions on the survey did address students' perceptions of and interest in engineering; however, the format of the questions is not aligned with some of the other findings in literature of successful surveys. For instance, we put them on a Yes/No basis rather than on a Likert scale.

Also, the pre and post test questions should mirror one another so a comparison can be made of students' responses before their participation in I2R and after. For example, the pre-survey used in the water scarcity session asked students to list ways engineers play a role in water scarcity, but did not repeat this question on the post-survey. We should asses such questions on both surveys to determine content learning by comparing the responses before and after the session. These realizations are important to inform our goal of providing our students with a meaningful engineering experience and our program's long term effort of recruiting young women to STEM fields. In general, we suggest a transformation of survey items like the summary included in Table 4.

Table 4: Suggested Transformation of Survey Question Format.

Previous Survey Item	Proposed Survey Item
Do you know what engineering is? (Yes/No)	I can describe what engineering is (5-point Likert scale)
Tell us what you think engineers do. (Open ended)	I can describe what engineers do (5-point Likert scale)
Do you think you could be an engineer? (Yes/No)	I could be an engineer (5-point Likert scale)
Would you encourage your friends to participate in I2R? (Yes/No)	I would encourage my friends to participate in I2R (5-point Likert scale)

In addition, our coding of the open-ended responses allowed us to develop some examples of proposed revisions to survey questions to address students' perceptions of engineering.

I think that engineering is...

- Improving life (5-point Likert scale)
- Making things (5-point Likert scale)
- Building things (5-point Likert scale)
- Working with machines (5-point Likert scale)
- Fixing things (5-point Likert scale)
- Designing (5-point Likert scale)
- Inventing (5-point Likert scale)
- Other...

To be an engineer I would have to...

- Be smart (5-point Likert scale)
- Like computers (5-point Likert scale)
- Enjoy math (5-point Likert scale)
- Enjoy science (5-point Likert scale)
- Have an engineer in my family (5-point Likert scale)
- Enjoy making things (5-point Likert scale)
- Be good with machines (5-point Likert scale)
- Be able to create new things (5-point Likert scale)
- Other...

The “other” blank at the end of the questions would still allow students to input additional free responses while the data is not yet at saturation. These types of questions will remain easy for the students to answer, and will allow for better data analysis than our previous assessments.

7. CONCLUSIONS AND RECOMMENDATIONS

Assessment of outreach programs especially with a focus on student learning is an important but challenging task. In this baseline analysis of our program we found that the content of the assessments was not designed with the specific intention to measure students’ perceptions of engineers. We found that many of the questions asked simply about what had occurred during the activity, but did not probe students’ deeper understanding of what they had participated in or if they were able to make any connections/applications of those experiences to real life. This leaves us unable to confidently report that our program is meeting its goals based on data. In addition, the survey that we used can be improved for better data analysis. For example, many questions were put on a Yes/No scale rather than a Likert scale. Open-ended questions were included such as, “tell us what you think engineering is,” and “tell us what you think engineers do,” but we did not prepare a rubric for evaluating responses to these questions in advance. To keep the surveys short and data analysis easy, we coded these responses to develop similar Likert scale questions. Our desire to create a more appropriate assessment design prompted a literature search for surveys that have been created and used successfully for similar purposes. These assessments have provided examples of more effective ways of assessing such as using Likert scale questions to measure students’ perceptions of engineering both before and after the programming and also embedding questions that address conceptual understanding within the supporting documents used during the hands-on activities. The development of a more rigorous assessment of our program will allow us to adopt a stronger methodological framework for analyzing the responses to our questions.

Based on this preliminary work and a review of other assessment tools, we have several recommendations for the improvement of the current I2R assessment strategy:

- Redesign survey instrument based on existing/valid models and per recommendations made in this paper
- Imbed assessment questions into content assessment on knowledge that allow students to express conceptual understanding of both content and their perceptions of what engineers are and do
- Prepare rubrics for additional evaluation pieces such as student artifacts and written student reflections

8. FUTURE WORK

As an outreach program, there are constraints based on the resources available. All of these recommendations require additional effort and time, so we aim to continue this work by designing an evaluation process that balances the time it takes to implement it with the results that are gained. We recognize the challenge of making such assessments work within the constraints that exist in any engineering outreach programming. The resources we aim to improve can then be used to drive change and improvement in our programming along with a more thorough understanding of how our work through is influencing students’ perceptions of engineering. This is of value in the attempt to improve the access of K-12 students to engineering in a meaningful way.

REFERENCES

Assessing Women and Men in Engineering (AWE). AWE instrument user guide—pre-college surveys. (2009). Retrieved from www.aweoneline.org

Fitzpatrick, V. R., Groh, J.L., Holloway. B.M. (2011). Partnering with university faculty and students to design engineering outreach sessions for middle school students. Proceedings from Women in Engineering Program Advocates Network Annual Meeting. Seattle, WA.

Gibbons., S. J., Hirsch, L.S., Kimmel, H., Rockland, R., Bloom, J. (2004). Middle school students' attitudes to and knowledge about engineering. Proceedings of the 2004 International Conference on Engineering Education.

Hirsch, L. S., Gibbons, S. J., Kimmel, H., Rockland, R., Bloom, J. (2003). High school students' attitudes to and knowledge about engineering. Proceedings of the 2003 Frontiers in Education Conference.

Jeffers, A. T., Safferman, A. G., Safferman, S. I. (2004). Understanding K-12 engineering outreach programs. *Journal of professional issues in engineering education and practice 130*(2), 95-108.

Rockland, R., Kimmel, H., & Bloom, J. (2002). Engineering the future: enhancement of pre-engineering programs through outreach. Proceedings of the 2002 International Conference on Engineering Education.