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Engineers as Teachers: Bringing Cutting-edge Math and Science Topics into Underprivileged Classrooms via Student and Professional Engineers

Abstract

Since its inception in 2006, Iridescent’s mission has been to foster curiosity, confidence, and a love for science and engineering in underserved children by utilizing undergraduate, graduate, and professional engineers as instructors in the community. Iridescent serves 3rd-7th grade low-income Hispanic and Black students and their families in the greater Los Angeles area. Our approach is to train volunteer engineers to teach cutting edge science to students and their families. This approach leverages a vital, yet untapped resource, engineers, to address the science, technology, engineering, and math (STEM) achievement gap. Engineers become long term volunteers, developing relationships with the children, and bringing valuable social capital into high-need areas.

Through our partnership with the University of Southern California (USC), engineering undergraduates enroll in “Engineers as Teachers” and receive 3 units of technical elective credit for participating in our training program. During the 16-week training undergraduate engineers partner with graduate students, faculty and professional engineers and learn to break down complex ideas into simple lessons, identify learning objectives, design aligned experiments and assess learning through a pedagogical theory-based approach. Throughout the training, engineer volunteers develop a story that pervades four to five lessons. Story topics are based on volunteering engineers’ research field so that they can share their expertise with the participating community.

To bring research-based STEM topics to the community, volunteer engineers work in pairs to develop lessons and experiments from their field. They then present their lessons and experiments to the whole training group which, in turn, offers suggestions on explanations, experiment design, and how to present the overall concept. Volunteers use an online collaboration site to comment on lesson plans, reflect on their teaching, and post new ideas and material.

Volunteer engineers come away from their experience with three main areas of impact. 1) They are empowered by inspiring others. “It is really a big deal to be working with students at a young age so they can be excited about what they're learning and so these students can be really ambitious for the future.” 2) They learn important lessons in management and public speaking. One volunteer observed, “This is a really useful skill because I’m sure later on in my career I’ll have to explain what I do to an audience that doesn’t necessarily have a background in my field.” 3) They learn more about their own field. One engineer commented: “The day to day life as a student at USC is a lot of theory. When we actually get to go into these classrooms, we’re actually…taking the theories we learned in our books and applying them to small models…”

This paper provides rationale for using engineers to deliver content to underprivileged communities, including the benefits to both the communities and the engineers. It outlines the engineers’ training that includes in-depth discussions and applications of established instructional theory and strategy. A key feature of Iridescent’s model is incorporating feedback and evaluation. We employ a multi-method research approach to evaluate the program’s impact.
on the volunteer engineers by using formative, summative, and self-reflective assessments, as well as interviews. Previous data from the program participants and impact numbers are presented and implications and expected outcomes for the program are discussed.

Introduction

In 2006-07 of the 1.5 million bachelor's degrees awarded that year, only 5% were awarded to the fields of engineering and engineering technologies. Furthermore, the representation of female and minority students in the areas of science and engineering remained, and continues to remain disproportionate. Females and ethnic minority students in STEM careers have been underrepresented for the past 30 years. In 2008, degrees in STEM awarded to women was only 18% while the representation of African-American and Hispanic students combined accounted for only 11% of bachelor’s degrees, far below their combined 28% share of the general population. Underrepresentation continues into the workforce in these areas as well. Without the representation of minorities and women in science and engineering, the United States is endangering its competition in the global economy.

In order to encourage participation in a dedicated and difficult field, much must be done to change the perception of science and engineering by minorities and women. Improving attitudes toward and achievement in science require continued classroom experiences in STEM, extracurricular activities involving STEM and the encouragement of others significant in a student’s life. The formal education system does not have the capacity to provide STEM curriculum intervention enabling minorities and women course and career opportunities in STEM. BEST (Building Engineering and Science Talent) has determined a “framework of design principles as a first approximation of what it takes to succeed over time in demanding educational and social environments. Programs designed to increase diversity in STEM courses and careers should address several areas. “The areas include, but are not limited to:

1. **Challenging content:** Academic enrichment in science and mathematics
2. **Personalization:** Contextual learning that enhances personal meaning and motivation to learn.
3. **Defined Outcomes:** College readiness experiences through on-campus or other college-connection events.
4. **Engaged Adults:** Substantive, ongoing professional development in science and mathematics for teachers, including ongoing contact with content experts.
5. **Sustained Commitment:** Broad-based, collaborative partnerships that promote high expectations and a college-going culture.

Through working with student engineers at the University of Southern California, and the continued participation of parents and families, Iridescent addresses all areas listed by Building Engineering and Science Talent in order to inspire and equip underprivileged students to pursue STEM careers.

Program Overview
By working with engineers at the university level, Iridescent provides families with challenging content and college readiness experiences; key components to increasing the participation of minorities and women in STEM courses and careers. Iridescent trains engineers to develop and teach hands-on, Family Science Courses to underserved children and their parents. The program has been successfully implemented in Los Angeles, the Bay Area and Salinas and shown to improve participants’ interest in science, content knowledge and self-efficacy. The Family Science Courses are designed and taught by engineers to families at schools in the evenings. Topics illustrate the real-world applications of Physics and range from Cardiovascular Mechanics to Bird-flight Aerodynamics. Each Family Science Course consists of five evening sessions of two hours each. Families are invited (including younger siblings). Formative assessments such as Exit Slips (three questions checking for content understanding) are conducted at the end of every session. Pre and post tests are conducted in each Family Science Course. Food is provided at every session. Instruction is translated into Spanish if the majority of families are Hispanic and non-English speaking. Since Iridescent’s incorporation in January 2007, 200 engineers have undergone science communication training and conducted 132 workshops reaching ~4000 underserved children and parents.

Related Work

We draw from the following to develop a powerful program for our diverse stakeholders:

**Family Science:** Examples of Family Science programs include the EQUALS Family Science Program, the Australian Family Science Project, 4-H and the Hands-On Science Outreach program. Others such as the Open Classroom and the National Science Foundation’s (NSF) Out of School Science Experiences have structured learning experiences that families undertake in formal and informal settings. These family-based programs have been shown to be particularly important in boosting the achievement of underserved students.

**Parent Leadership Programs:** Much research shows that parents support their child’s education more readily when they feel empowered. Key factors that enable sustained parental involvement are: 1) incorporating parent feedback into the program design; 2) providing continued support after training and gradually reducing the support over 3-4 years.

**Broadening participation:** There are many models of involving diverse audiences in STEM. Some models include the 2000 conference, "The Challenges and Impact of Human Genome Research for Minority Communities" that allowed minority communities to share their thoughts on genomics. Another example is the Science Museum’s Dana Centre, London, which conducts programs on science, technology and culture that are co-created by the Dana Centre and Chinese and Afro-Caribbean communities.

**Public engagement and understanding of science:** The NSF-funded, Portal to the Public Initiative, develops and tests program models that engage scientists and public audiences in face-to-face interactions that promote appreciation and understanding of current science research.

**Professional development for scientists:** BA Perspectives (coordinated by the British Association for the Advancement of Science) encourages scientists, engineers and social scientists to explore the social and ethical implications of their research and trains them to interact with the public at a poster session in a science festival. Another example is the website, "Communicating Science: Tools for Scientists and Engineers" created by the NSF and the American Association for the Advancement of Science to help scientists and engineers communicate better with the public. The website offers webinars, how-to tips for media interviews, strategies for identifying public outreach opportunities, and workshops for scientists and engineers who are interested in learning more about science communication.
Cyber learning: Ice Stories (an Exploratorium project) connects citizens to scientists using the Web. The project encourages researchers to blog and webcast their research in Antarctica. It also encourages readers to comment and discuss the posts with the scientists.

Benefits to Engineers: “My Work Inspires Many”

The Family Science Courses enable engineers to directly impact the STEM pipeline by serving as role models and providing meaningful science learning experiences to the public. The engineers develop their public speaking and leadership skills and a deeper understanding of their own field while communicating complex concepts to large, diverse audiences. The Family Science Courses also add deeper meaning to the engineers' work through personal validation, connection and gratification from clarifying complex topics for the public. Thus engineers willingly volunteer significant amounts of time to the Courses (80-100 hours/four months). In addition, they become regular, long-term volunteers bringing valuable social capital to high-need areas.

Benefits to Community

Parents are required to come and participate in the experiments with their children. The goal is to educate and empower the parents so that they can better support and further their child’s education. Thus parents continue the learning that is initiated in the Family Science Courses by providing relevant books, directing their children to relevant science programs on television, taking their children to museums and science centers and by participating in additional science activities.

Recruiting Engineers

Through a strong partnership with the University of Southern California, engineering undergraduates enroll in “Engineers as Teachers” and receive three units of technical elective credit for implementing the Family Science Courses. Every semester we recruit undergraduates by presenting in different classes, conducting social events and design competitions. We maintain a database of volunteers, alumni and potential candidates and send out a monthly newsletter. We encourage applications from women and minorities by advertising through campus diversity organizations. Undergraduates are paired with volunteering graduate students or professional engineers. We recruit the volunteers using Idealist.org and VolunteerMatch.org. We have recruited 20 undergraduates and 20 volunteers every year through these methods.

Interested candidates go through a rigorous screening process. They are required to: 1) provide a statement explaining why they are suited to this project. This stage tests applicants’ interest, ability to self-analyze and write; 2) present a five-minute lesson on a topic of their choice. This tests their comfort with public speaking, preparation, time management, and initiative.

Training

Engineers go through 16 weeks of training during which they teach two Family Science Courses. Training addresses: how people learn, audience types and motivations, strategies for working with various age groups and designing engaging multi-media experiences. The training also
gives engineers a model for effective direct instruction, opportunities for them to practice their new skills and ways for them to self-evaluate their teaching.

Engineers are given a lesson plan template and that helps them break down complex ideas into simple lessons, identify learning objectives, design learner-directed experiments and assess learning (figure 1). Topics are chosen based on participating engineers’ research and experience. Two well established lesson plan approaches are utilized: the Learning Cycles lesson approach\textsuperscript{22} and Inquiry-based instruction\textsuperscript{23}. Engineers practice teaching using few technical terms, real-world analogies and multi-media to ensure understanding for audiences with limited education. Engineers learn to use assessment practices such as graphic organizers to ensure families make significant knowledge gains\textsuperscript{24}. Engineers also design a pre/post assessment in order to measure their effectiveness. Weekly preparation includes a reading assignment, instruction planning and reflective practice. Engineers are observed by Iridescent staff in each session and given feedback on how to improve their communication. The course syllabus with weekly training details and the lesson plan template can be accessed from our website (www.IridescentLearning.org), under “Programs” and “Engineer Training”. 
## Iridescent Lesson Plan about VISCOSITY

<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>KEY CONCEPTS AND VOCABULARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>What will your students be able to do?</td>
<td>What 3-5 key points will you emphasize?</td>
</tr>
<tr>
<td>1. Students will be able to define what viscosity is.</td>
<td></td>
</tr>
<tr>
<td>2. Students will be able to define Reynolds number as inertial over viscous forces.</td>
<td></td>
</tr>
<tr>
<td>3. Students will be able to use Reynolds number to explain how size affects whether an organism sees a sticky or inertial environment.</td>
<td>• Viscosity is the stickiness of a fluid</td>
</tr>
<tr>
<td></td>
<td>• Animals move differently depending on how viscous (sticky) or inertial (density) a fluid is</td>
</tr>
<tr>
<td></td>
<td>• Reynolds number is inertial/viscosity</td>
</tr>
<tr>
<td></td>
<td>• The size of an animal changes its Reynolds number</td>
</tr>
</tbody>
</table>

### CONNECTION TO THE BIG IDEA
How does the objective connect to the big idea?

How a fluid feels to animals of different sizes

### ASSESSMENT
How will you know whether your students have made progress toward the objective? How and when will you assess mastery?

Pre and post drawing of how a bacteria uses flagella to move and how fish/whales use fins to move. We will use the Animal Locomotion poster as a guide.

### OPENING (2 min)
How will you communicate what is about to happen? How will you communicate how it will happen? How will you communicate its importance? How will you communicate connections to previous lessons?

Hi! How is everyone doing? Let's review what we have been learning so far! What are we here to learn about in this course? Right! How animals move! Can anyone tell me what we learned in the first lesson? Right! We learned about fluids and how air and water are both fluids and how a swimming fish is similar to a flying bird. What did we learn about in the second lesson? Right! A property of a fluid, called Density! Can anyone remind me of what density is? Mass/Volume. Alright! What did we learn about in the third lesson? Buoyancy! What kind of model did we try to make? A neutrally buoyant fish! Awesome! Today we are going to learn about a second property of a fluid, called viscosity. We will also learn how tiny animals swim in the water. Can someone give me an example of a very tiny animal? Has anyone heard of Plankton? “Plankton” is a general term for organisms that drift or swim weakly. Show them with pictures and videos. We will learn how small animals like plankton move through the water, and how their movement is different from large animals like whales and birds.

### MATERIALS
What materials will you need for your lesson?

- 1. Tape
- 2. Pipe cleaners
- 3. Marbles
- 4. Lead shot
- 5. Play-do
- 6. Twist-ties
- 7. Foam pads
- 8. Karo syrup (enough to fill 2 small testing tanks)
- 9. Water tanks
- 10. Karo syrup/water tanks
- 11. Stop watches
- 12. Zip lock bags/paper cups/bowls
- 13. Scissors
- 14. Coloring Pens/Crayons/Pencils
- 15. Paper to draw designs on
- 16. Microscopes
- 17. Plankton tow critter
- 18. Tidepool copepods
- 19. Prepared slides
- 20. Pre-assessment

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Figure 1: First page of completed sample lesson plan on Animal Locomotion: Viscosity
Feedback and Support

Throughout the 16 week training, participating engineers practice teach their lessons in front of the rest of the class and elicit feedback. They present their lesson plans and assessments in the same manner they would in the classroom while the class (participating engineers and the instructor) gives feedback. They receive feedback on the number of concepts, child-friendly language, experiment design, and the overall clarity with which the topic is being taught.

Participating engineers are partnered with an “Alum Mentor”. An Alum Mentor is an engineer who has previously been through the “Engineers as Teachers” program and taught Family Science Courses. Alumni Mentors meet with participating engineers four times over the 16 week training session to review the experiments in the lessons and to give overall tips on teaching a Family Science Course. Alumni Mentors use their experience to review engineers’ story outlines and most importantly their experiments. Alum Mentors ensure the experiments are fun, open-ended, aligned with the learning objectives, sufficiently challenging to be engaging and aligned with our philosophy of teaching engineering as redesign by allowing participants the freedom to tinker, redesign and learn about the concepts through application and trial and error.

In addition to in-person feedback via the course and Alumni Mentors, participating engineers also use an online collaboration tool called Basecamp. Through Basecamp, engineers post lesson plans, assessments and videos of themselves teaching and solicit feedback from experts, instructors, and peers.

During the actual Family Science Courses, Iridescent staff complete a thorough Instructor Evaluation which assess the instructor on his or her abilities to address topics discussed in class, what the instructor did well, and what they can improve.

Lastly, participating engineers reflect on their own teaching by studying videos taken by their partner during the courses. Participating engineers are required to self-assess their teaching and write what they did well during their instruction, and what they can improve.

Evaluation

We use a multi-method research approach to evaluate program impact on families’ and engineers’ understanding and behaviors. We gather data using surveys, interviews, pre- and post-test scores, concept mapping, and fieldwork. We administer pre and post assessments about families’ STEM experience and knowledge, social capital and interest and engineers’ public communication skills. We measure how multiple contextual factors such as socio-economic factors, quality and accessibility of experts and educational and technology resources affect participants’ interaction with the curriculum and activities. Outcomes for the families include developing the motivation to learn about science and to think of themselves as science learners. Ongoing involvement leads to positive changes in communication at the individual, family and community levels. Measurable outcomes include a greater than 80% increase in families’ STEM knowledge, interest (see figure 2) and collective efficacy i.e. people’s confidence that they can unite to support their children’s science education.
Figure 2: These examples were from the Girls and Mothers only Course that was led by two women aerospace engineers. After the Family Science Course, when asked to draw an engineer at work, the participants drew girls and women in their responses.

We use Instruction Evaluations during the Family Science Courses and Post-training Engineer Surveys in order to measure participating engineers’ improvement, understanding, and perceptions. Completed evaluations are used by participating engineers in order to improve their instruction strategies and practices. Evaluation measurements include how well the instructors tie the lesson into an overall story across all lessons, whether the instructor defined new terms and concepts in non-technical terms, and what varied methods the instructors used to teach the material. The evaluation also provides specific suggestions and strategies for improvement.

Engineers are also evaluated after they have completed the training in order to measure their perceptions of engineering instruction, their ability to communicate complex ideas to the public, their understanding of lesson planning and effective instruction, and the community in which they taught (figure 3).
Figure 3: Participating Engineers’ responses to the attitudes and perceptions evaluation.

Measurable outcomes for the engineers include a greater than 60% gain in: 1) awareness of their strengths and weaknesses while interacting with the public; 2) understanding motivations and learning styles of diverse audiences; 3) communication skills with the public. While these evaluation practices are our most recent, evaluation methods are constantly being analyzed and revised for improvement.

Impact

Iridescent’s Family Science Courses impact the STEM community by: 1) creating sustained learning experiences that help Los Angeles Schools broaden family participation in STEM; 2) fostering collaborations between universities and Los Angeles School that bring current research to the public; 3) impacting the STEM pipeline by bringing social capital to underserved communities; 4) developing and implementing technology-based, data-driven, evaluation and resource-allocation tools; 5) identifying factors that develop persistent participant interest in STEM.

To date, we have developed a detailed 16-week training program that enables engineers to communicate complex ideas to the public. 160 engineers and 40 student-engineers have gone through our training and developed curricula on 14 topics (see figure 4). We have developed an engineer evaluation that measures changes in communication, leadership skills and cultural awareness. Through interviews with six engineers and surveys with 12, we have seen that the two main reasons why engineers dedicate significant time and effort to the Family Science Courses are: 1) an opportunity to improve their science communication skills; 2) to impact the science, technology, engineering and mathematics (STEM) pipeline.
Engineers as Teachers Alum

Alumni of the Engineers as Teachers program have several opportunities to stay involved, and often take advantage of these opportunities. Alum can continue to teach subsequent Family Science Courses. Alum can also serve as an Alumni Mentor, giving feedback and support to participating engineers. Lastly, Alum can serve as recruiting ambassadors by presenting to student groups and classes and by recommending participation in the program to peers.

Scalability and Growth

We have documented key aspects of the program for scaling. We have a detailed engineer training syllabus, lesson planning template, engineer observation forms, detailed guidelines and checklists for engineers, volunteers, translators, parents, teachers and school administrators and 70 existing lesson plans. We have developed a resource-allocation tool, the Urban School Needs (USN) Map that enables us to choose partner schools based on their need and interest in long-term partnerships. We have adapted the model for scalability by conducting seven courses in the Bay area in 2007 and 2008 and one Family Science Course in Salinas with the Monterey Bay Aquarium in 2009. The primary lesson from these experiences was the importance of having a strong education partner at each site (Peninsula Bridge program for the Bay area and the Monterey Bay Aquarium for Salinas). With a strong partner, Iridescent’s support role just entailed recruiting and training the engineers and providing comprehensive lesson plans. All other support activities were successfully conducted by the partner organizations.

Our vision is to have Iridescent sites in major metros within the United States and third world countries where there are high-need communities and strong resources (such as universities and
technical industries). Scaling up will present challenges of magnitude, breadth and programmatic complexity32. The current Iridescent model has gone through three stages that will enable it to scale successfully: 1) We have shown it to be effective – i.e. we have credible evidence that the innovation has measurable and desirable effects; 2) We have shown that the initial successes can be replicated in settings similar to those in the scale-up site; 3) There is an established institutional mechanism (Iridescent partnering with universities and community organizations) to accomplish and sustain the scale-up.

Our three-year goal is to establish sites in the San Francisco Bay Area and in New York City. The Bay Area site is currently being established (Fall 2009) and we aim to start the New York City site in Fall 2010.

Our global vision is to adapt our curricula and develop teacher-support systems for implementation in third-world countries. We are currently partnering with a rural school system, Navodaya Vidyalayas, in India to test implementation of our curriculum at two sites. On successfully conducting the pilots in two Navodaya Vidyalayas, we will work with the administration to gradually deploy our curriculum within their system of 600 schools.

Conclusion

Iridescent’s Engineers as Teachers program incorporates all of BEST’s recommendations of challenging content, personalization, well-defined outcomes, engaged adults and sustained commitment to increase diversity in STEM courses and careers.

By utilizing University undergraduate and graduate students as instructors, Iridescent increases the exposure of challenging, STEM based curriculum to a diverse group of students. Engineers as Teachers also ensures that lessons are aligned with participating engineers’ current research, and all lessons include a design-based experimental portion allowing instruction to be personalized. By working with student-engineers, families receive direct contact with college students and with college-ready curriculum. Families are also engaged in lessons as they learn alongside their children. Additionally, most families attend all 5-session courses allowing them sustained access to engineering and science content and to undergraduate and graduate engineers creating high expectations for learning, and a college-going culture6.

Iridescent’s model using University graduates and undergraduates to deliver challenging content to the public can be replicated at different Universities with an engineering or higher sciences department. Iridescent is currently replicating this model in Monterey, Salinas, the Bay Area, and New York.
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