

STEM Outreach Using In-House And Mobile Demonstrations

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Abstract

Science, Technology, Engineering and Math (STEM) education is one of the most discussed topics among educators today. The current high-tech world requires more scientists and engineers than ever before. Although many strategies have been introduced to motivate students to enter technical fields, additional approaches are needed to continue to attract students. In this paper, the Joint School of Nanoscience and Nanoengineering (JSNN) STEM Outreach Program is described. JSNN uses university resources to promote hands-on STEM demonstrations utilizing both in-house and mobile assets. The in-house program uses an annual open house event (“Gateway to Science”) as well as facility tours and STEM videos and for students who are unable to attend an open house, such as Gateway to Science, or take part in a field trip to visit the JSNN facility, “hands-on” science and engineering demonstrations are brought to their schools to encourage a greater focus on STEM disciplines. The part of the JSNN STEM outreach program that visits schools is the Mobile Nanotechnology Education Laboratory, a.k.a. “the Nanobus”. The considerations for designing these outreach programs and student responses have been analyzed. The analysis provides insights for continuous improvement to keep the programs vibrant and interesting.

Keywords: STEM, Nanotechnology, Mobile laboratory, Science, and engineering demonstration

1. Introduction

To develop an outreach program to promote STEM education, the literature was reviewed, and the following questions were identified and addressed.

1.1 Who should we try to reach and how?

Survey results show that students who have an interest in science at an early age are more likely to graduate from an engineering or science program. Muller et al showed that most students make their decision regarding their future career major before the age of fourteen (Muller et al., 2013). The current job market for STEM graduates is a motivating factor (Hossain & Robinson, 2012), however, a personal interest in STEM subject matter and peer influ-

ence may also be factors (Phinney et al. 2005). In addition, a STEM outreach program should also include roles for supportive parents and teachers and feature a diverse group of instructors/demonstrators to effectively communicate the subject matter.

1.2 What type of activities would be most effective to reach students?

A STEM outreach program should introduce science and engineering concepts by stimulating students with hands-on experiences. Although software and web-based educational videos help generate interest in technical fields, to create a greater impact, a direct, hands-on experience is needed. Most higher education facilities have educational outreach programs, including tours and events (Cantrell & Ewing-Taylor, 2009; Innes et al., 2012; Pierre & Christian, 2002; Rivoli & Ralston, 2009). Unfortunately, too often these programs fail to reach large numbers of students. To engage large numbers of participants properly, an educational program that visits schools is more likely to have a greater impact on appropriate age group students.

1.3 What concepts would be best to engage students?

There are many possible science and engineering demonstrations that might have suitable STEM content and that might engage students. For example, UCLA used a computer-intensive teaching program (Palacio-Cayetano et al. 1999). However, Hofstein showed that for science education, laboratory methods work better for understanding STEM concepts and can promote important science learning outcomes for the students (Hofstein & Lunetta, 2004).

1.4 How to teach STEM topics?

To design a STEM outreach program, Kesidou et al. recommended (Kesidou & Koppal, 2004) three key ideas:

- Align your outreach efforts with relevant content standards.
- Pay attention to what students are thinking.
- Take advantage of instructional strategies that work.

Even if the Kesidou et al ideas are implemented, at-

tendance at STEM outreach programs may still be low. Effective learning methods may be the most critical components of attractive programs. Among many learning methods in STEM education, active learning has been proven effective (Freeman et al., 2014). Also, to present science in an exciting way, many groups tried to connect STEM programs to future career paths.

2. JSNN STEM Outreach Program

The Joint School of Nanoscience and Nanoengineering (JSNN) was established by North Carolina A&T State University (NC A&T SU) and The University of North Carolina at Greensboro (UNCG) with the expectation that it would be a leading-edge education and research facility. Also, there was an expectation of STEM education outreach and participation in community economic development. JSNN conducts two types of STEM outreach activities shown in Figure 1.

The Gateway to Science events have been held since 2010 and the Nanobus has been operating since 2015.

2.1 In-house Program (known as the Gateway to Science)

To promote STEM education, JSNN holds an annual open house event known as “Gateway to Science” as part of the North Carolina Science Festival. At the Gateway to Science event, approximately thirty science and engineering demonstrations are set up throughout the JSNN facility. The demonstrations are staffed by M.S. and Ph.D. students from the school’s Nanoscience and Nanoengineering majors. Also, attendees receive tours of the laboratories and are invited to watch videos about nanotechnology and scientific careers. An example of the demonstrations is shown in Figure 2.

The photograph in Fig. 2 shows a JSNN student demonstrating shear thickening fluid to students and community members. At each of the 30+ demonstrations, the JSNN graduate student in charge of the demonstration acts as a docent explaining the science and engineering principles involved and answering questions from the attendees. All demonstrations used in the Gateway to Science event are intended as hands-on activities. For example, the 3-D printer demonstration features toys

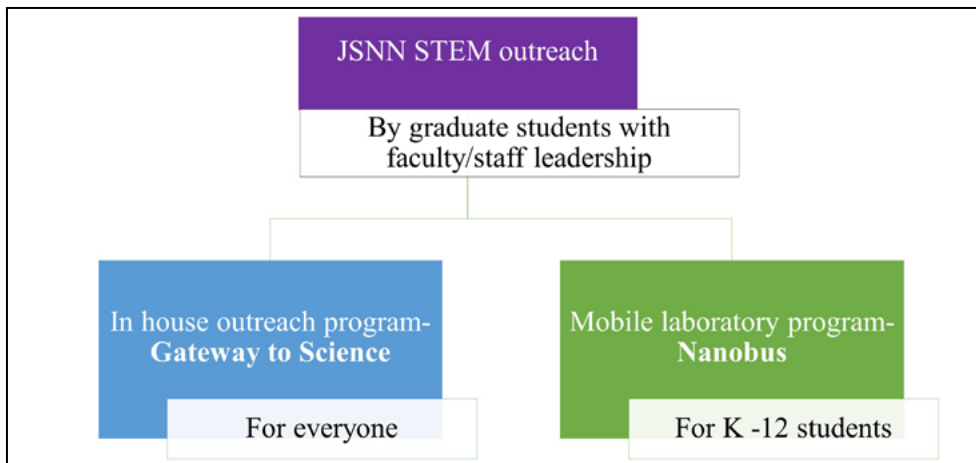


Figure 1. JSNN STEM outreach programs



Figure 2. A shear thickening fluid demonstration at the Gateway to Science 2018 event.

made by the printer that can be handled and examined to encourage questions and teach the technical principles involved. Some of the demonstrations shown in the Gateway to Science event are also part of a mobile outreach program described in the next section.

2.2 Mobile Laboratory Program-Nanobus

Like other science and engineering facilities, JSNN routinely conducts facility tours for school field trips. A field trip to the facility usually involves a tour of the laboratories as well as the videos previously described. Science and engineering demonstrations are not done with routine field trip groups because they would disrupt JSNN educational activities for our students who need to be in class or in the lab. Relying on field trips alone is an inadequate outreach strategy for an entity like JSNN because field trips are difficult for schools to organize and undertake. To schedule a field trip, a school needs to find time in the academic schedule that would enhance the

curriculum rather than eliminate or compress a portion of the curriculum and a school must find the money to pay for transportation and possibly food for their students.

To address these problems, JSNN developed a mobile STEM outreach program to take science and engineering into the schools rather than waiting for students to be able to visit our facility. The “Mobile Nanotechnology Education Laboratory” (a.k.a. the Nanobus) was developed to bring STEM subjects directly to schools and minimize the time commitment and expense of field trips. To design the Nanobus program, an interdisciplinary student and faculty team evaluated possible forms for effective outreach programs.

Although a mobile laboratory can incorporate some of these concepts, there are a few additional issues that a mobile laboratory needs to consider. For example, it is expected that all materials used in Nanobus demonstrations are safe since they are part of the “hands-on” program. The Nanobus program uses a simple rule: All ma-

terials must be purchasable in a grocery store. The use of inexpensive and easily available materials makes it easy for students to interact with the demonstrator and, at the same time, the students will be able to repeat similar demonstrations for parents at home. Also, since the demonstrations are transported on a small bus and must be able to be unpacked, set-up and re-packed after the demonstrations are complete, it is essential that all demonstrations are either structurally robust or that they can be re-built/re-assembled within minutes if damaged due to packing, transportation or use occurs.

The Nanobus program uses JSNN doctoral students to carry out the demonstrations. Each team member spends one or two semesters on the team. New members are brought into the team each semester and team members are encouraged to propose new demonstrations to add to the Nanobus program. The effectiveness of the Gateway to Science event is assessed by surveys, but the Nanobus program is assessed through discussions and correspondence with teachers (although occasionally students provide written feedback as well).

The Nanobus (see Fig. 3a) limits its visits to schools and events that are typically within an hour travel time of JSNN’s central North Carolina location (Fig. 3b). Special emphasis is made to include rural schools and events directed at reaching students who may be under-represented in STEM fields. The Nanobus visits K - 12 schools but makes the most visits to elementary and middle schools. The program runs on Wednesdays during the Fall and Spring semesters. Nanobus visits last from ninety minutes to four hours depending on the venue and the request of the hosting organization. The Nanobus program started in 2015. The team typically does 15 to 20 events each academic year and estimates that it has reached over 10,000 students at its events.

Although JSNN supports the Nanobus program through the time and effort of its personnel, to begin the program, it was necessary to obtain philanthropic support in order to purchase the bus and build the initial set of demonstrations. The Nanobus initiative was funded by Duke Energy Foundation and ThomasBuilt Bus. The bus is specially manufactured to carry equipment and materials necessary to demonstrate scientific and engineering phenomena as well as transport the educational team to schools and community events.

Six JSNN doctoral students and a staff member comprise the team and they present approximately ten science and engineering demonstrations (Fig. 4) at each school or event. The list of demonstrations used by the Nanobus is shown in Table 1. Demonstrations are selected based on the venues and expected ages of the attendees. For example, venues that are outside in windy conditions prevent demonstrations like surface tension and torsional flow. Indoor venues accommodate most demonstrations but some demonstrations like “Elephant Toothpaste” and “Extinguishing Candles with Carbon Dioxide” are more in-

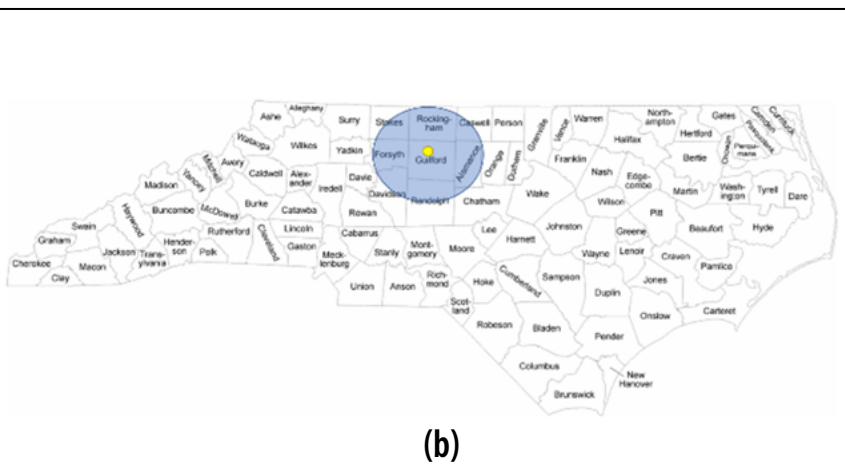


Figure 3. a) JSNN Nanobus with crews. b) The blue highlighted area is the region where the Nanobus operates in North Carolina (courtesy of waterproofPaper.com). The yellow dot on the map indicates JSNN's location.

interesting for elementary and middle school ages than for high-school age students.

Table 1: Nanobus demonstrations

Demonstrations based on scientific principles are:

1. Surface Tension — Bubble creation and manipulation through surface tension. Surface tension is shown as a force. Size effects demonstrated using a dollhouse glass.
2. Magnetic Food - The presence of iron in breakfast cereal can be detected with a magnet.
3. Ferrofluid - Ferromagnetic particles align with a magnetic field making the field visible.
4. Pendulum wave generator.
5. Pouring out Candles - Synthesize Carbon Dioxide from baking soda & vinegar.
6. Elephant Toothpaste - Breakdown of hydrogen peroxide (H₂O₂) into water and oxygen.
7. The detection of Nanopore effects in balloons using flavoring like vanilla and mint

Demonstrations based on engineering principles

1. Shear thickening fluid — Shown using a cornstarch and water mixture on a speaker.
2. Lenz's law — Shown by dropping a magnet through a copper pipe.
3. Bernoulli's principle - Shown using balloons and a Bernoulli bag.
4. The electrical conductivity of food - Shown using "Makey Piano" software and bananas.
5. Creating Structures with a 3-D Printer.
6. Torsional Flow — Shown by making smoke rings using a modified trash barrel as a smoke cannon.



Figure 4. Nanobus demonstrations at Mcleansville Elementary, Guilford County, 2017

3. Considerations for Design of JSNN STEM Outreach Program Design and Improvement

The Nanobus demonstrations have focused on scientific and engineering phenomena that elicit the question "How did you do that?" from students. The demonstrations that show these unexpected phenomena attract the most attention, questions, and participation. The demonstrator can then explain the principle behind the demonstration.

To conduct outreach activities effectively, trained personnel are needed. Science and engineering students have proven to be effective outreach educators in the literature (Laursen et al. 2007). Student-educator participation depends upon alignment of academic schedules and proper preparation. Students can play many significant roles in outreach programs including syllabus development, demonstration design, build and maintenance, event management, and feedback analysis. Because of the complexity of the student-educator role and the other demands on a student's time, it is necessary to develop a formal structure to effectively organize the outreach team. Therefore, the JSNN STEM outreach program is structured as a method for satisfying the teaching requirement for JSNN doctoral students.

Maintaining a continuous improvement scheme (by evaluation and assessment) is also important for an out-

reach program to be meaningful. Comprehensive assessment and evaluation results that measure the effectiveness of these program activities in meeting their goals and objectives are suggested and should be reported for future use (Bogue et al. 2013). For example, Penn et al. (Penn et al. 2007) described a microscopy camp outreach program where participants drew the atomic structures of salts they saw under the microscope and Wiebe et al. used a survey instrument (Wiebe et al., 2013) to record a change in student attitude toward science as a future career path.

To ensure continuous improvement in the JSNN STEM outreach programs, feedback from attendees (particularly teachers) is requested. After attendance at the annual Gateway to science event, attendees are asked to complete a survey (Appendix). The surveys are analyzed to determine the quality of interactions and the relative popularity of the demonstrations so that the program can be improved each year. After the Nanobus visits to schools, teachers send comments to the Nanobus coordinator regarding their students' interest in the demonstrations as well as feedback on other parts of the program (e.g. the effectiveness of the presenters). The teacher's feedback is usually in the form of letters or email. The Nanobus is particularly interested in the teacher's opinions about the demonstrations that the students like best and ways that the program can improve its effectiveness.

4. Assessment of the Program

Assessment of the JSNN STEM outreach program is complex and requires feedback from various sources. The most important source of feedback is the attendees. Sometimes interesting comments were received at the point of delivery. For example, a student was so excited about one of the demonstrations during a Nanobus school visit that he said to the demonstrator "You're a magician!" and the demonstrator replied, "No, I am a scientist". Although happy responses from students are gratifying, the JSNN STEM outreach program staff uses surveys at the Gateway to Science event and written comments from teachers after Nanobus visits to assess the program. The Nanobus visits don't lend themselves to surveying the attendees because interactions are limited by the large crowd size and short interaction time driven by class schedules in the schools. Teacher feedback after visits has been very helpful to understand which demonstrations are the most popular and informative and whether the demonstrators are effective at communicating with the students. Occasionally, feedback directly from the students also received in the form of thank you notes. They provide insight into what demonstrations they enjoyed most (often with illustrations) as well as a description of what they learned. The most interesting thank you note that the program received was from a North Carolina middle school student who summarized the problem STEM educators face and the hoped for results. The key sentence from the note was "To be honest, I thought it was going to be a boring science lecture, but it surprised me in the best way possible."

The opinions and observations of JSNN's doctoral student demonstrators have been essential to increase the effectiveness of teaching complex STEM concepts. Although there are many examples, three examples of program changes made by student-educators include a computer model created by one of the student demonstrators was added to the pendulum demonstration to more clearly illustrate the wave motion observed. JSNN students have continually improved the demonstrations to assure quick set up and reliability. The JSNN outreach program is currently on the fourth incarnation of the speaker for the Non-Newtonian/Shear Thickening fluid demonstration. Each iteration has made the demonstration more robust and easier to set up and operate while students are simultaneously asking questions. Students have added new demonstrations based on their interests or the expected interests of the attendees like the DNA of strawberries and the rain cloud demonstrations performed at Gateway to Science.

Figure 5 shows the results of a survey of 36 attendees for the 2015 Gateway to Science event. The news of the event was circulated by various means to reach the school students and others. An important observation is that oral communication was the major contributor to

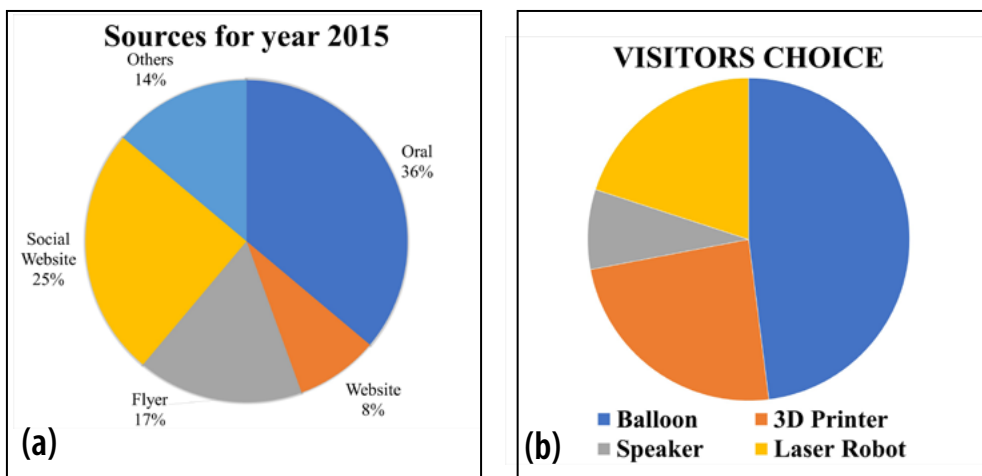


Figure 5. 2015 Gateway to Science Event Survey a) how did attendee learn about the event? b) the most liked demonstration

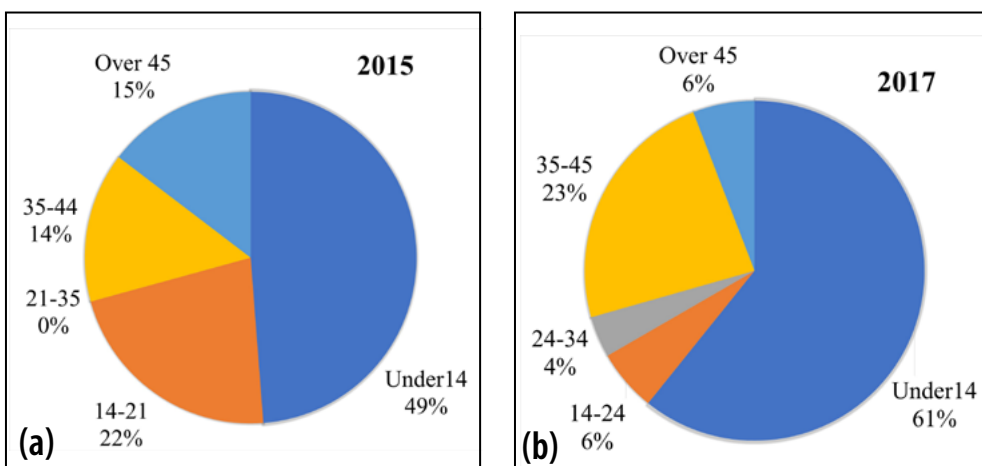


Figure 6. Attendee age ranges in the year a) 2015 and b) 2017 at Gateway to Science event

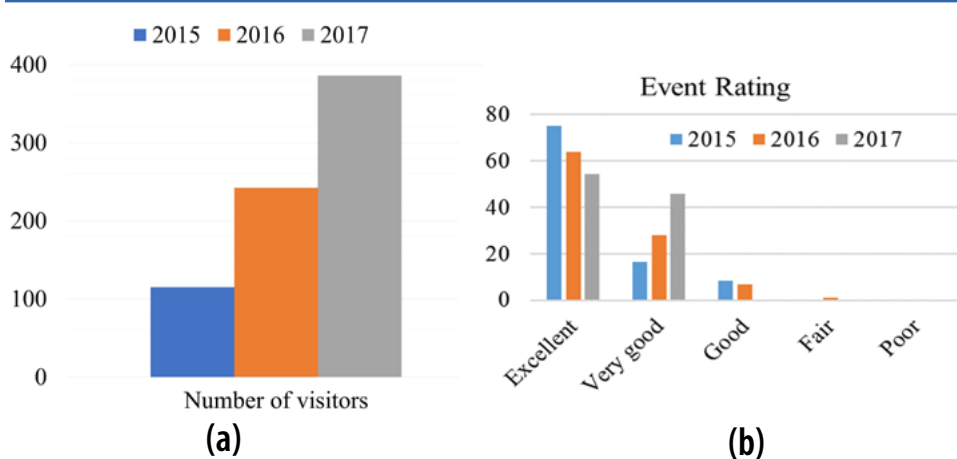


Figure 7. a) visitor attendance and b) event rating at Gateway to Science events

bringing attendees to the event. Social media is also an important means to attract people from different age groups. Visitors to the event gave a more than 90% positive response to the question about interaction and participation in the demonstrations. The visitors also gave high approval ratings (90%) for the event and indicated interest in future events. The survey asked which demonstrations the attendees liked best.

Although there may be several factors involved, our survey indicated that attendees liked the demonstrations that involved balloons as well as demonstrations with instruments such as a 3D printer and laser robot. Comparable results were obtained in 2017 with a sample size of 51.

The largest number of attendees at the 2015 Gateway to Science Event was in the under-fourteen

age group. However, there was also a large number of 35 – 44 and over 45 people in attendance. The data indicates students visited the event with their families. In 2017, there was more advertising for the event and more direct outreach to schools and this approach yielded a higher percentage of under-14 attendees (Fig. 6). The number of visitors has increased each year for the Gateway to Science event (Fig. 7a). The overall rating for each year continues to be very high (Fig. 7b).

5. Conclusion

A model is described that promotes hands-on STEM demonstrations utilizing both in-house and mobile assets. The in-house program uses an annual open house and school field trips to provide “hands-on” science and engineering demonstrations as well as facility tours and STEM videos to encourage a greater focus on STEM disciplines. The Mobile Nanotechnology Education Laboratory, a.k.a. “Nanobus”, is an outreach program that visits schools and provides a similar experience to students who can’t attend an open house or take part in a field trip. The program concepts and design have been assembled to prompt the question from attendees “How did you do that?” To encourage hands-on and fun engagement followed by a discussion of principles. The programs and student responses have been analyzed and the results used to provide continuous improvement to keep the programs fresh and interesting.

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Appendix

Sample survey questions

1. How would you rate today's event overall?
 - a. Excellent
 - b. Very good
 - c. Good
 - d. Fair
 - e. Poor
2. How did you find out about our event?
 - a. Word of mouth
 - b. JSNN website
 - c. Flyer
 - d. Social website
 - e. Others
3. Did you interact with a scientist as a part of today's event?
 - a. Yes
 - b. No
 - c. Not sure
4. Your age group
 - a. Under 14
 - b. 14-21
 - c. 21-35
 - d. 35-44
 - e. 44 and above
5. What is your favorite festival activity?
6. What improvement would you like to see at the next year event?