AC 2012-5017: THE DEVELOPMENT OF AN OUTREACH ACTIVITY INTRODUCING MIDDLE AND HIGH SCHOOL STUDENTS TO NANOTECHNOLOGY AND CARBON NANOTUBES

Tasha Zephirin, Purdue University, West Lafayette

Tasha Zephirin is a doctoral student in the Department of Engineering Education at Purdue University. She received her B.S. in electrical engineering from Virginia Tech and her research interests involve incorporating concepts from learning theories, international and global education, and multicultural education to best advise the development of STEM education to diverse audiences across the education continuum.

Mr. Mohammad Mayy, Norfolk State University
Dr. Monica Farmer Cox, Purdue University, West Lafayette
Ms. Tanya S. David, Norfolk State University

Center for Materials Research, IGERT MNM

The Development of an Outreach Activity Introducing Middle and High School Students to Nanotechnology and Carbon Nanotubes

Abstract

The Integrative Graduate Education and Research Traineeship in Magnetic and Nanostructured Materials (IGERT-MNM) supports the development of an interdisciplinary graduate training program centered on the design and study of these novel materials. The program is a collaborative effort between University Norfolk State University, Purdue University, and Cornell University. Interdisciplinary technical training occurs in four areas: (1) Physics and Nanotechnology of Metamaterials, (2) Magnetic Multilayer Nanostructures, (3) Nanoscale Magnetic Systems, and (4) Engineering Education Research. Graduate Trainees at participating institutions will participate in research under one of these four areas. A primary goal within the engineering education research component is to identify ways to transfer graduate program elements and the technical theory behind nanoscience and nanotechnology to multiple educational stakeholders (e.g., K-12 students, undergraduate students, graduate students, and industry professionals) via curricula, workshops etc.

This paper will describe the development of an outreach activity for middle and high school students by Graduate Trainees, including initial approaches and revisions based on anecdotal observations made from previously conducted workshops. Reflections from the Trainees will also be included in an effort to understand how doctoral students with technical backgrounds develop pedagogically-sound materials that translate their research to new educational audiences. The primary goal of the developed workshop is to create an awareness of carbon nanotubes (CNTs) amongst participants and how their use in future applications within the field of nanotechnology can benefit our society. The workshop provides a guided discussion via PowerPoint presentation and hands-on activities about what is meant by nanotechnology, the relevance of nanotechnology and CNTs in our everyday lives, allotropes of carbon, and how carbon sheets can be manipulated to form different CNTs (e.g. single-walled, multi-walled, etc.). With an audience of educators and outreach coordinators, a secondary goal is to demonstrate how educational frameworks such as “How People Learn” (Bransford et. al., 2002) and “Backwards Design” (Wiggins & McTighe, 2008) were incorporated in the design of the workshop.

Introduction

Three Graduate Trainees (i.e., doctoral students funded by the IGERT-MNM) were primarily responsible for the development of this workshop. Tanya David and Mohammad Mayy are Ph.D. students in Material Science Engineering (MSE) at Norfolk State University, and Tasha Zephirin is a Ph.D. student in Engineering Education at Purdue University. All three Trainees participated in a “Best Practices in Teaching and Learning” Module, led by Dr. Monica Cox at Purdue University via videoconference, as part of the IGERT-MNM program. This module aims to introduce Trainees in traditional MSE Ph.D. programs to terminology, concepts and frameworks utilized in educational research. As a primary goal within the engineering education research component of the program is to identify ways to transfer graduate program elements and the technical theory behind nanoscience and nanotechnology to multiple educational stakeholders, Dr. Cox shared an opportunity to develop a workshop for the 2011 National Educators Workshop (NEW) – Converging Technologies and Disciplines. The goal of this conference is to facilitate the sharing of material science focused demos and workshops that can be used in the classroom by educators. With the assistance of a graduating Trainee, the three Trainees took the initiative to develop a workshop for use by middle or high school educators as an introduction to the topic of carbon nanotubes.

The technical content was determined by Trainees at Norfolk State University. Evidence that technology develops rapidly can be seen in our everyday lives when considering the use of pagers in the past to the prevalence of smartphones today. With all of this new technology at hand, young students are curious about the science behind these technologies, and the answer will not be found in the typical school curricula science books[1, 2]. The developed workshop presents the opportunity to give a basic understanding of some of the new rising technology's building blocks such as graphene and carbon nanotubes[3, 4] and how their uses in future applications within the field of nanotechnology can benefit our society. The Trainees sought to incorporate demonstrations and examples (from their past and present experiences) of concepts they found to be both important and potentially interesting to middle and high school audiences. Technical content was framed within two educational frameworks widely accepted by members of the engineering education community, "How People Learn"[5] and "Backwards Design."[6] Introduced in the "Best Practices in Teaching and Learning" module within the Trainees' professional development seminar, these frameworks were also mentioned in the workshop led by Trainees with an audience comprised of educators of middle and high school students.

Workshop Overview

The learning objectives of this workshop are listed in Table 1. The workshop provides a guided discussion via PowerPoint presentation and hands-on activities about what is meant by nanotechnology, the relevance of nanotechnology and carbon nanotubes (CNTs) in our everyday lives, allotropes of carbon, molecular structures and applications of graphite, graphene and CNTs, and how grapheme sheets can be manipulated to form different CNT structures. It was also explained how these structures allow an extra electron that "floats" outside, giving the materials a metal-like conductivity. Hence, the relatively small size of these structures at the nanoscale provides the advantage of constructing devices which are small, fast, and capable of holding large amounts of data.

Table 1: Workshop Learning Objectives

At the end of this workshop, participants will be able to: (1) Describe characteristics of carbon nanotubes (CNTs). (2) Identify potential applications for CNTs in everyday life. (3) Describe key characteristics of nanotechnology. (4) Demonstrate activities and creative ideas for teaching about carbon nanotube structures (*for teachers only*)

Hands-on activities

In order to demonstrate how carbon atoms link to each other to form various types of shapes, ball-shaped commercially available cereal and tooth picks were used. Workshop participants were asked to link as many balls as possible, using the tooth picks, ensuring that every ball was connected to three other balls as shown in Figure 1. In the end, the structure would resemble a graphene sheet (see Figure 2).

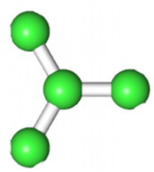


Figure 1: The central carbon atom is attached to another three carbon atoms.

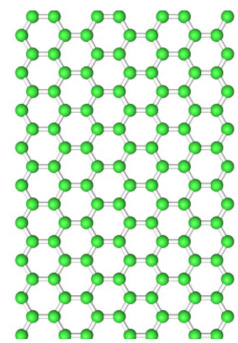


Figure 2: The graphene sheet. The balls are carbon atoms and the links are the bonds between the atoms.

For a simple way to understand the different CNT shapes, their conductivity, and their electron mobility, the graphene sheet image shown in Figure 2 was printed on a regular sheet of paper. The sheet can be folded to form a cylindrical shape that would resemble that of the CNT. Depending on the diameter and the direction of the fold (lengthways, width ways or corner to corner), it is explained how CNTs of different properties can be constructed for use in various devices or applications. A sample slide is shown in Figure 3.

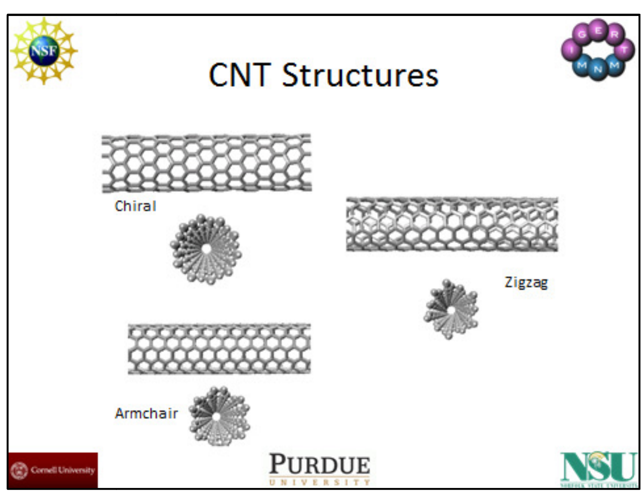


Figure 3: Slide showing different CNT shapes that can be formed depending on how the sheet is manipulated.

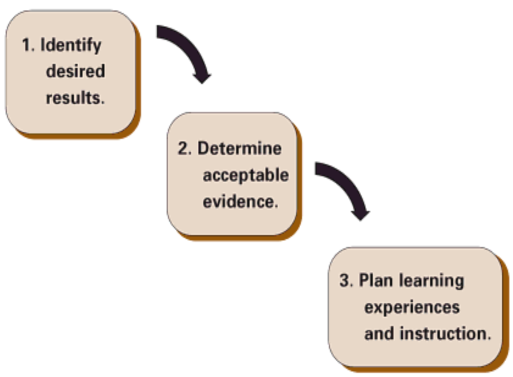
Development of Workshop

The Trainees worked remotely to develop and to edit the content of the workshop. Communication was maintained via email, videoconference, and video-calling software applications. Since the Purdue University Trainee was not as familiar with the technical content as Trainees at Norfolk State University, this provided the opportunity to determine how well the information would be communicated to an unfamiliar audience. This discussion led to the streamlining of content to align with the learning objectives and timeframe of the workshop. The Purdue University Trainee assisted the NSU Trainees in applying technical content to the selected educational frameworks.

Use of Educational Frameworks

Backwards Design Application

The general Backwards Design framework was used in developing the initial outline and development of the workshop[5]. Figure 4 displays the overarching purpose of the framework and the three-stage approach utilized.



- Identify desired results.
  – What do I want students to learn?
- Determine acceptable evidence
  – How will I know students learned what they were supposed to learn?
- Plan learning experiences and instruction
  – What experiences/activities/instruction can I include to make sure students learn what they are supposed to learn?

Figure 4: Stages of Backward Design[5] (p. 18)

In order to guide the development of the workshop, the design questions provided by Wiggins & McTighe were utilized as shown in Table 2.[5] The initial overarching learning goal for the workshop was to create an awareness of CNTs and how they are used in common applications within the field of nanotechnology to benefit society. More specifically, we wanted to discuss the concept of "scale" within nanotechnology as well as characteristics and applications of carbon nanotubes as shown in "Stage 1-Desired Results" of Table 2. The learning experiences and activities to demonstrate achievement of the desired results included a PowerPoint presentation, hands-on activities previously described, and example applications with which the target audience could relate. As this workshop was designed for use by middle and high school educators, we also intended to dedicate a small portion of the workshop to describing our selected educational frameworks. From this, the learning objectives listed in Table 1 were derived.

As a short, stand alone workshop, we decided on two forms of formative assessment. Acceptable evidence within the workshop would be determined by the caliber of questions asked during the workshop and a pre- and post- one minute brainstorm (written by participants on an index card) about how participants' defined the term "nanotechnology." In addition, presenters asked questions targeting key ideas in the workshop to determine participants' understanding of this content. It was identified that in the future, a formal survey would be used to determine how well concepts were understood by workshop participants.

Table 2: Design questions used to guide workshop development[5]

<table>
<tr><th colspan="2">Stage 1- Desired Results</th></tr>
<tr><td colspan="2">Goals:
To create awareness of carbon nanotubes (CNTs) and how they are used in common applications within the field of nanotechnology and their benefits to our society.</td></tr>
<tr><td>Understanding:
Students will learn how…
• Nanotechnology occurs at small (10^{-9}) scale
• Carbon nanotubes are allotropes of carbon
• Carbon nanotubes are potential building blocks for future technology
• Carbon nanotubes have desirable characteristics
Teachers will learn…
• How educational frameworks can be used to effectively develop workshops</td><td>Essential Questions:
• How small is "small" when talking about nanotechnology?
• What are current and future "building blocks" for technology?
• Are carbon nanotubes used in applications in which I am familiar?</td></tr>
<tr><td>Students (and teachers) will explore…
• Key nano-related terms (e.g., nanotechnology, allotropes, carbon nanotubes) and applications for carbon nanotubes
Teachers will learn…
• How to use educational frameworks to guide presentation of information</td><td>Students (and teachers) will …
• Describe characteristics of CNTs.
• Identify potential applications for CNTs in everyday life.
• Explain the importance of CNTs.
Teachers will …
• Demonstrate and create activities about carbon nanotube structures that can be implemented in a classroom setting.</td></tr>
<tr><th colspan="2">Stage 2- Assessment Evidence</th></tr>
<tr><td>Performance Task:
• Polling questions and rating of the caliber of questions asked
• One-minute paper (Pre- and Post-Workshop)</td><td>Other Evidence:
• Overall evaluation survey</td></tr>
</table>

Stage 3-Learning Plan
Learning Activities: ***Learning experiences and instruction will enable students to achieve these desired results via:*** • Guided discussion via PowerPoint • Hands-on activities throughout the presentation to ensure understanding of key concepts • Providing visual pictures with real life references that are familiar to the audience

"How People Learn" (HPL) Framework Application

The general principles identified in the HPL framework were also used to guide the development of the workshop[6]. An illustration of the four principles of the framework (i.e., knowledge-centered, learner-centered, assessment-centered, and community-centered) are presented in Figure 5.

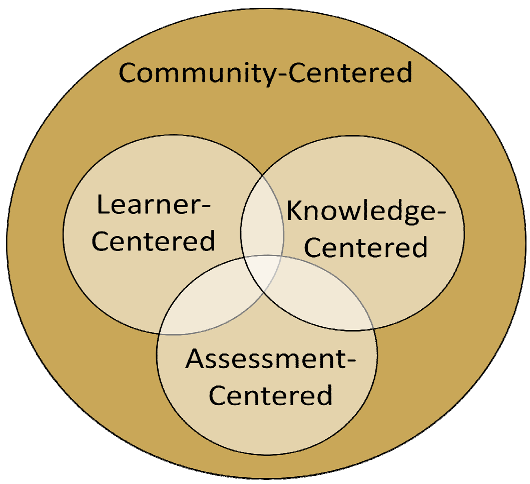


Figure 5: Four dimensions of the How People Learn (HPL) framework[6]

Table 3 summarizes how principles of the HPL framework were addressed in the development of this workshop. The knowledge-centered dimension (i.e., moving beyond mere memorization of academic content) was framed within the context of topics such as nanotechnology and CNTs. The sequence in which concepts were presented in the workshop was discussed frequently to ensure that the best understanding was achieved, and links were made among the bigger technical concepts. Initially, the idea of "building blocks" was not explicitly stated by the Norfolk State University Trainees, but on further questioning from the Trainee at Purdue University, it was discovered that this was a key idea. The assessment-centered dimension of the HPL framework was addressed in the Backwards Design discussion on assessment.

The learner-centered dimension was achieved by including hands-on activities to complement introduced concepts and to ensure student attention was not lost. Pictures and explanations that would pique the interest of a middle and high school student audience were used. For example, images of famous tennis players were shown before talking about potential applications of graphite within tennis racquets. Also, images shown at the nanoscale were accompanied with images of their macroscale application. When possible, anticipated prior knowledge of students was used to explain concepts. For example, for a quick understanding of "scale", the size of a carbon nanotube was compared to a human hair and then a house to demonstrate different orders of magnitude. An analogy of a runner also was used to describe how the speed of the free electron in carbon nanotubes varies based on the diameter size and the tradeoff between speed and duration. A runner (the electron) who starts running at a faster pace may run a shorter distance quickly and at high intensity (smaller carbon nanotube diameter corresponding to higher electron flow peak), but will tire (drop in electron flow peak) much quicker at a longer distance than a runner who starts slower (carbon nanotubes with larger diameters).

The community-centered dimension of the HPL framework was fulfilled in the manner in which the workshop was conducted. An interested and excited tone was employed by presenters, and they encouraged participants to interact with each other. Questions were encouraged throughout the workshop, especially as participants worked on the hands-on activities. With an audience of educators, sharing the teaching resources at the end of the workshop also facilitated additional discussions.

Table 3: Examples of HPL framework principles' application in workshop

Knowledge-Centered • Key Terms: nanotechnology, carbon allotropes, carbon nanotubes • Key ideas supported by PowerPoint slides • Order of concepts in presentation modified to ensure better understanding	**Assessment-Centered** • Questions to/from participants • One minute paper • Survey (to be developed)
Learner-Centered • Hands-on activities • Visual images and examples familiar to middle/high school students	**Community-Centered** • Leading questions asked by presenters to encourage participant interaction • Questions encouraged • Hands-on activities

Trainee Reflections on the Workshop

Since this was the first time that the workshop was presented, and since the lead presenters were graduate students with no prior educational research experiences, the Trainee in Engineering Education led the development of a reflection that would allow the MSE Trainees to self-reflect upon their experiences engaging within the workshop. In order to document each workshop delivery and continue to improve the workshop, the worksheet shown in Table 4 was developed and completed by workshop presenters.

Table 4: Self-reflection completed by MSE Trainees after the workshop

NEW Workshop Reflections

1) What aspect(s) of the workshop were well-received (i.e., seen as most valuable/clear/relevant?)

2) What aspect(s) of the workshop were not well-received?

3) Was there anything that educators identified that they would use immediately?

4) Briefly describe your presentation style and how you approached delivering the workshop

5) In future delivery of the workshop:
   a. How would I alter my presentation style, examples emphasized etc?

   b. How would I alter presentation content?

6) What were unexpected positives/surprises in delivering the workshop?

7) What unanticipated challenges were there in delivering the workshop?

General

What were the biggest conceptual hurdles faced:

1) trying to use educational frameworks in the development of the workshop

2) trying to communicate the use of educational frameworks to an audience of educators

Additional Observations/Comments

Workshop presenters (i.e., Trainees) thought that in general, the workshop was very well-received. Specifically, the hands-on activities were favored. The visual nature of the PowerPoint and how the pictures were used to frame examples was appreciated. As expected, educators were unfamiliar with educational frameworks, in particular the Backwards Design and HPL frameworks, presented in the workshop. Educators seemed to be appreciative of the exposure to these frameworks but additional time could have allowed presenters to discuss they were utilized in the development of the workshop they just experienced.

Educators identified that they would find ways to incorporate the hands-on activities in their classroom immediately. What surprised the presenters were comments from the educators about how they enjoyed the presentation and how the hands-on activities helped with understanding the presented concepts. In addition, some of the educators asked if they would come to their schools to present the same workshop.

As expected, in the first delivery the presentation was a little rushed, and it was discussed among presenters how explanations and content could be further streamlined to allow sufficient time for hands-on activities. An effort was made to ensure that most of the audience understood a concept or example before moving on.

An unanticipated challenge experienced by the presenters was underestimating the prior knowledge of the audience. All explanations were adjusted to assume minimal experience with the concepts being presented. The challenging parts of the workshop included describing how different graphene structures will have different properties for different applications. A graph that demonstrated electron flow for the different diameters of CNTs was also confusing, as participants did not understand what the graphs meant in relation to the size of the nanotubes and whether the graphs were all one configuration of nanotube. This slide was consequently simplified to reduce confusion.

When incorporating the educational frameworks into the development of the workshop, it was challenging to take the first drafts of the workshop outline and break up and rearrange content to maximize understanding when delivering the content. It also was challenging to address concepts of nanotechnology and CNTs without making the presentation too technical, and it took additional effort to find pictures and images that would best complement the content being delivered. However, the extra time and effort was worth it as confirmed by comments from workshop participants. In addition, from the pre- and post- one minute brainstorms, the presenters observed that while some participants had a naive understanding of nanotechnology at the beginning of the workshop, all participants showed an improved understanding by the end of the workshop.

It was not difficult to explain the educational frameworks to the educators once examples were used to help them understand what the different concepts in the framework meant. Hand-outs can be developed to make this delivery more effective to educators who are not familiar with the frameworks presented.

Framed within the context of the strengths, weaknesses, opportunities, and threats (SWOT) framework, the team identified the following points about the workshop:

Strengths

- Incorporation of educational frameworks into workshop development
- Appreciation of educational research by technical engineering graduate students and middle/high school educators

Weaknesses

- Workshop only delivered to middle/high school student educators and not middle/high school students

Opportunities

- Interest from educators presents new avenues to conduct the workshop and conduct additional assessments with a student audience

Threats/Challenges

- Potential conflicts with students who perceive that they must be "experts" in both the technical and engineering education environments.

Future Work

At this time, the workshop has been presented to an audience of middle and high school educators twice (a group of nine and a group of eight, respectively) by Trainees across the three IGERT universities. The authors intend to further fine-tune the content and delivery of this workshop. In addition to an audience of educators, we also intend to present this information directly to middle and high school students as more insight can be gained into the effectiveness of the workshop and translation of the educational concepts if the presenters interact directly with the target audience.

Acknowledgements

This work was developed under the Integrative Graduate Education and Research Traineeship in Magnetic and Nanostructured Materials (IGERT-MNM), supported primarily by the National Science Foundation under grant #0966188.

Bibilography

[1] U.S. Department of Education (2008). Evaluation of evidence based practices in online education: A meta-analysis and review of online learning studies. USDE Publication Number ED-04-CO-0040. US Government Printing Office, Washington, D.C.

[2] Jonathan, R. (2011). Online education as a toll good: An examination of the South Carolina virtual school program. *Computers & Education*, *57*(2), 1583-1594.

[3] Datta, S. S., Strachan, D. R., Khamis, S. M., & Johnson, A. T. C. (2008). Crystallographic Etching of Few-Layer Graphene. *Nano Letters*, *8*(7), 1912-1915. American Chemical Society. doi:10.1021/nl080583r

[4] Blake, P., Brimicombe, P. D., Nair, R. R., Booth, T. J., Jiang, D., Schedin, F., Ponomarenko, L. A., et al. (2008). Graphene-Based Liquid Crystal Device. *Nano Letters*, *8*(6), 1704-1708. American Chemical Society. doi:10.1021/nl080649i

[5] Wiggins, G., & McTighe, J. (2005). *Understanding by Design* (2nd ed.). Prentice Hall.

[6] Bransford, J.D., Brown, A.L., & Cocking, R.R. (Eds) (1999). *How People Learn: Brain, Mind, Experience, and School.* Washington, DC: National Academy Press.