Strategies and Methods for Improving Understanding of Advanced Concepts in Introductory Nanotechnology Course

TOPASNA, Daniela M

Department of Physics and Astronomy, Virginia Military Institute, United States

Abstract

In this paper we present selected/various methods of instruction that are used in the undergraduate nanotechnology introductory course. The goal is to help students with all learning styles[1] (aural, kinesthetic, or visual) to comprehend and retain the new material, as well as be engaged during class. Nanotechnology and nanoscience represent a rapidly developing field, highly complex and interdisciplinary, that seeks to understand and manipulate structures at the nanometer level. The course is offered as a technical elective and one of the challenges in teaching this introductory course is having students from various disciplines and with various science backgrounds. In addition, the nature of the subject suggests use of not only lectures and Power Point presentations, but also practical, lab, and hands-on activities. The topics that are usually covered include fabrication and characterization techniques, nanostructures, biomimetic concepts, and social and ethical implications.[2] Every time the class is offered, it is adapted to existing resources and to students' background and interests. Therefore, we include specific activities to supplement the lectures: combination of short exercises, videos, new developments, career opportunities, applications, demos and lab activities, and visits to research labs. These types of activities help students learn new and complex topics and enhance their writing and communication skills. Similar approach can be used in other courses, such as modern physics, quantum, optics, and even in the introductory physics classes.

Keywords: *higher education, nanotechnology, class activities, communication skills, students engagement*

1. Introduction

The goal of this paper is to describe examples of methods of instruction employed in the introductory nanotechnology course that were implemented in support of various learning styles.

The importance of STEM education is clearly expressed by the US Department of Education: "youth are prepared to bring knowledge and skills to solve problems, make sense of information, and know how to gather and evaluate evidence to make decisions."[3] STEM education is also an important part of US National Nanotechnology Initiative, which "is helping to build the nanotechnology workforce of the future, with focused efforts from K–12 through postgraduate research training."[4] Nanoscience and its applications in nanotechnology represent a highly interdisciplinary field that impacts every aspect of life and technology. As such, it has become common for many schools, at all levels, including undergraduate level, to introduce concepts or to offer courses related to nanoscience and nanotechnology. At Virginia Military Institute (VMI), such a course has been offered every other year for over a decade. Its goal is to introduce students to the relatively new and fast developing field of nanotechnology. It is offered by the Department of Physics and Astronomy, as a junior level (third year) course with the general physics as prerequisites. The course satisfies the technical elective requirement for all STEM departments and as such it is popular amongst STEM students. Initially, the course was based on textbook[5], lecture, and PowerPoint (Microsoft Office) presentations. With students having various science background knowledge and interests, the delivery and understanding of course material was therefore affected in uniformity and pace. While PowerPoint presentations facilitated most comprehension and retention through text and visual content, it was clear that additional methods were needed to increase student engagement and to deepen their learning levels. The pedagogical strategy was to deliver the course material through a holistic approach, by addressing all four learning styles in the VARK model[6, 7]: visual, aural, read/write and kinesthetic. As a consequence, the course has evolved from a lecture type to a balanced combination of readings, lectures, demos, and hands-on activities. The optimized format benefits students who are now active learners and who stay engaged during class. Each time the class is offered, it is adapted to existing departmental resources and to students' backgrounds and interests. We include specific activities to supplement the lectures: combination of short exercises, videos, discussions of new developments, career opportunities, applications, demos and lab activities, and visits to research labs. These types of activities help students learn and retain new and complex topics and enhance their writing and communication skills. A similar approach can be used in other courses, such as modern physics, optics, and even in the introductory physics classes.

2. Methodology and Implementation

The VMI course "Introduction to nanotechnology" covers a variety of topics that are organized in modules, such as nanofabrication and characterization techniques, nanostructures, applications, biomimetic concepts, and social and ethical implications. Each module is based on several subtopics; for example, the unit on nanostructures has separate lectures, each on fullerenes, carbon nanotubes and graphene, quantum dots, and nanoparticles. Similarly, the module on fabrication includes micro- and nanofabrication, micro-contact printing, nanoimprint and scanned probes lithography, and self-assembly methods. Over time, the course has evolved from lecture only to a combination of lecture and various other activities that satisfy students' preferences of learning styles. This transformation mainly occurred as a result of early observations that lecture alone was not as motivating and exciting to capture students' attention. Gradually, the delivery of the course content has been adapted to utilize existing resources in the department and in the thin films research lab, and to effectively address students' educational backgrounds and interests.

2.1 Visual Activities

The course uses PowerPoint presentations, especially in the initial introduction of a new topic in class. Videos are also an important educational tool for this course. Examples include short video segments that illustrate fabrication of integrated circuits, focused ion beam lithography, or explanations of basic principles of scanning tunnelling microscope and atomic force microscope[8, 9]. There are numerous similar instructional videos that can be found in a cursory search[10, 11]. Quite often, students take initiative and find related videos.

2.2 Aural Activities

There are many opportunities in this course to engage students in brief but meaningful discussions on a topic. These discussions are often triggered by recent developments that are reported in the media or in specialized publications. They are also initiated as part of the classroom activities. Students are given a list of professional organizations and societies, or journals, from which they can select topics to be discussed. In addition, they are encouraged to bring for discussion their own topics of interest. Not surprisingly, students find novel and relevant developments that they share for the benefit of the entire class.

Another useful activity that solicits student participation and engages them in discussions is represented by short calculations or estimations, with emphasis on units. For example, students are asked to calculate the size of a magnetic bit based on the magnetic storage density. Quite often, they first reply that they have not yet learned that formula. When prompted that they do not need a special formula, they realize the simplicity of the calculation. The exercise reinforces students' self-confidence when using simple and fast calculations.

Meaningful discussions are also carried on societal and ethical implications of nanotechnology, effects on the environment, health, climate, and the military and political ramifications[12]. A simple illustration of such discussion is debating the benefits versus detriments of using silver nanoparticle in antibacterial coatings on various consumer products.

Students show great interest when career opportunities in the field of nanotechnology are presented. They inquire how their education and skills relate to the field of nanotechnology. They learn how almost any field is impacted by it and how it benefits from developments in nanoscience. Besides engineering and medicine, entrepreneurship in nanotechnology represents one of the top career choices students want to learn about.

2.3 Read/Write Activities

The first assignment in this course is reading and writing a brief essay on Richard Feynman's talk "There is plenty of room at the bottom".[13] Students are asked their opinion on the challenges posed by Feynman and to reflect on the progress of the field, when at the time the laser itself was still developed in research labs.

The course requires readings on selected chapters and topics from the textbook[5]. Additional readings are suggested from a list of books on related topics. Occasionally, students are assigned to find review articles or do literature search for a specific information. For example, for each of the nanostructures studied, students are asked to find an application and describe its characteristics. The information is then shared with the rest of the class.

Besides the typically required homework and tests, students are also asked to select and write a paper on a topic that sparked their interest. This can be a technique, structure, or other nanotechnology related issues and applications. In addition, they produce a presentation that is given to the entire class at the end of the course. As an educator, this represents the highlight of the teaching and learning process as it demonstrates the student's ability to select a favourite topic and understand it well enough to describe it to their peers. Students are proud of their presentations and they seriously take ownership of their product. For the instructor, it is rewarding to see that students do adventure successfully beyond the topics covered in class. This is also a great opportunity for them to learn on their own about the applications of nanoscience in their respective field of study.

2.4 Kinesthetic Activities

Simple activities take place in the classroom while more advanced demos, lab activities, and hands-on experiments are performed in the Thin Films Lab. These active learning experiences are most favored by students. For some of them, it is the first time they have the opportunity to observe and handle equipment and instruments in a research lab. They also learn about the lab safety and protocols and about methods of data and image analysis. The activities, experiments, and instruments routinely used in the course include:

- Fabrication of thin films by spin coating and characterization by UV-Vis-NIR spectrophotometry
- Contact photolithography
- Fabrication of gold nanoparticles[14,15]
- Scanning Electron Microscope (SEM) - photonic bandgaps (bird feathers, butterfly wings)
- Materials optical microscope – Janus particles
- Hands-on activity to build carbon allotropes molecules and structures[16]
- Demo on Atomic Fore Microscope (AFM)
- Handling and visualizing components of computer hard drive and disk

Occasionally, students get the chance to visit and observe first-hand research at Virginia Tech NanoEarth Center.[17] They are given brief presentations on real-world, high-impact applications of nanotechnology and on career and internships opportunities. Students interact with faculty, staff, and graduate students; they go through lab tours and get hands-on on modern instruments such as Transmission Electron Microscope (TEM) or SEM. This is one of the most motivating and inspiring activity of the course.

3. Discussion

Implementing activities that address various learning styles allows more students to stay motivated and engaged in the course. As active learners, they become confident and take responsibility in their education. Besides accumulating new knowledge, they develop their writing and communication skills, learn about the latest developments and applications of nanotechnology, and what career opportunities are available.

Given the vastness of resources in nanoscience and nanotechnology, the selection of topics and activities could be an overwhelming process. A gradual approach is advisable, starting with a small selection that can be easily adapted and implemented in the course and based on departmental resources and educational goals. The examples of methods and activities listed in this paper can be adapted to other courses such as modern physics, optics, or general physics.

A formal analysis of the students' preferred learning style(s) has not been performed. The author plans to do so in the near future. However, based on students' comments throughout the years, the most favored activities were the field trip and the lab experiments, followed by the students' presentations. Least favored were listening and following the lecture presentations. Initially, so was writing the final paper. However, once the paper was finalized, students were proud of their accomplishment and understood the necessity and benefits of the process.

The type of activities presented in this paper are simple, efficient, adaptable, and easy to implement in other STEM courses. They are beneficial to students as they broaden and deepen their knowledge of a field, keeps them engaged during class, and hones their writing and communication skills.

Acknowledgments

We are grateful for the time and excellent instruction given to VMI cadets by Prof. Matthew Hull and his colleagues at Virginia Tech NanoEarth.

References

[1] McGlynn, K.and Kozlowski, J. “Kinesthetic learning in science,” Science Scope 40, 9, 2017, p24-27

[2] “VMI Academic Catalogue”, p 147. Retreived from https://www.vmi.edu/media/content-assets/documents/registrar/VMI-Catalogue-2021-2022.pdf (2021).

[3] U.S. Department of Education, “Science, Technology, Engineering, and Math, including Computer Science”. Retrieved on 19 January 2022 from https://www.ed.gov/stem?utm_content=&utm_medium=email&utm name=&utm_source=govdelivery&utm_term=

[4] National Nanotechnology Initiative, “About the NNI”. Retrieved from https://www.nano.gov/about-nni January 2022

[5] Di Ventra, M., Evoy, E., and Heflin, J. R. “Introduction to Nanoscale Science and Technology”, Kluwer Academic Publisher, 2004.

[6] Fleming, N. D. and Mills, C. E, “Not Another Inventory, Rather a Catalyst for Reflection”, To Improve the Academy, Vol. 11, 1992,p 137.

[7] Fleming, N., and Baume, D. “Learning Styles Again: VARKing up the right tree!,” Educational Developments, SEDA Ltd, Issue 7.4, Nov. 2006, p4-7.

[8] Beam, J. C. “Virtual Lab Content” Retrieved from https://www.wecanfigurethisout.org/VL/contents.htm , 2022

[9] Nanowerk https://www.nanowerk.com/

[10] For example, “An Introduction to Microfabrication via Photolithography”, Jornal of Visualized Experiments. Retrieved from https://www.youtube.com/watch?v=B0g1_rr-ApI January 2022.

[11] Micro Nano Technology Education Center (MNT-EC) https://micronanoeducation.org/

[12] For example, Sparrow, R. “The Social Impacts of Nanotechnology: an Ethical and Political Analysis”, Bioethical Inquiry, 6, 2009, p13-23.

[13] Feynman, R. P. “There’s Plenty of Room at the Bottom”, Engineering and Science, Volume 23:5, February 1960, p 22-36.

[14] Poinern, G. E. J “A Laboratory Course in Nanoscienc and naotechnology CRC Press, 2014.

[15] Bergandine, D., Gelsthorpe, T., Koker, T., Muskin, J.,and Ragusa, M. ”Gold and Silver Nanoparticles”, Lab rretrieved from http://nano-cemms.illinois.edu/materials/gold_and_silver nanoparticles full.html January 2022

[16] For example, Indigo Instruments https://www.indigoinstruments.com/ Retrieved January 2022

[17] Virginia Tech ICTAS NanoEarth https://nanoearth.ictas.vt.edu/ Retrieved February 2022