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STRATEGIES FOR INTEGRATING NANOSCALE SCIENCE AND TECHNOLOGY INTO COLLEGE BIOLOGY

Joy E. Stewart[1] and David Devraj Kumar[2]

[1]Department of Science, Willis Holcombe Center, Broward College, 111 East Las Olas Blvd., Fort Lauderdale, FL 33301; *jstewart@broward.edu* ; *Tel.: 954 201 7320 / 954 651 0508 (cell)*
[2]College of Education, Florida Atlantic University, 3200 College Avenue, Davie, FL 33314.

ABSTRACT

This paper addresses strategies for integrating nanoscale science and technology into college biology curricula. Relevance of nanoscale science and technology to college biological science education, appropriate topics, objectives, pedagogical strategies, assessment, and related curriculum and instruction issues are presented. Research involving nanoscience and nanotechnology has led to awareness that nanoparticles and objects manufactured at the nanoscale (1 – 100 nanometers) have the potential to facilitate advances in medicine, manufacturing, information technology, and environmental sustainability (Rocco, 2004). It is evident that advancements in science and technology will require science education at the college level to shift focus from the microscale to the nanoscale.

Keywords: *nanoscience, nanotechnology, nanoparticles, biological science, education*

INTRODUCTION

Advancements in nanoscale science and technology are accelerating the development and application of technology and making significant changes in the way we perceive basic science. New waves of global advances in medicine, information technology and consumer products are due to innovations in nanotechnology. Nanoscience is the scientific study of materials one billionth of a meter in size, and nanotechnology represents various technologies to develop materials of extra high precision and dimensions on the scale of one-billionth of a meter[1].

The following examples might help readers to comprehend the nano-size factor[2]. The width if one DNA molecule is approximately 2.5 nanometers. An average human hair has a diameter of approximately one hundred thousand nanometers. Ten hydrogen atoms lined up side by side can fit within a space of one nanometer[3]. Figure 1 may also enhance comprehension of the nano-size factor where the scale-up factor applied from left to right compares the nanometer scale object to familiar objects.

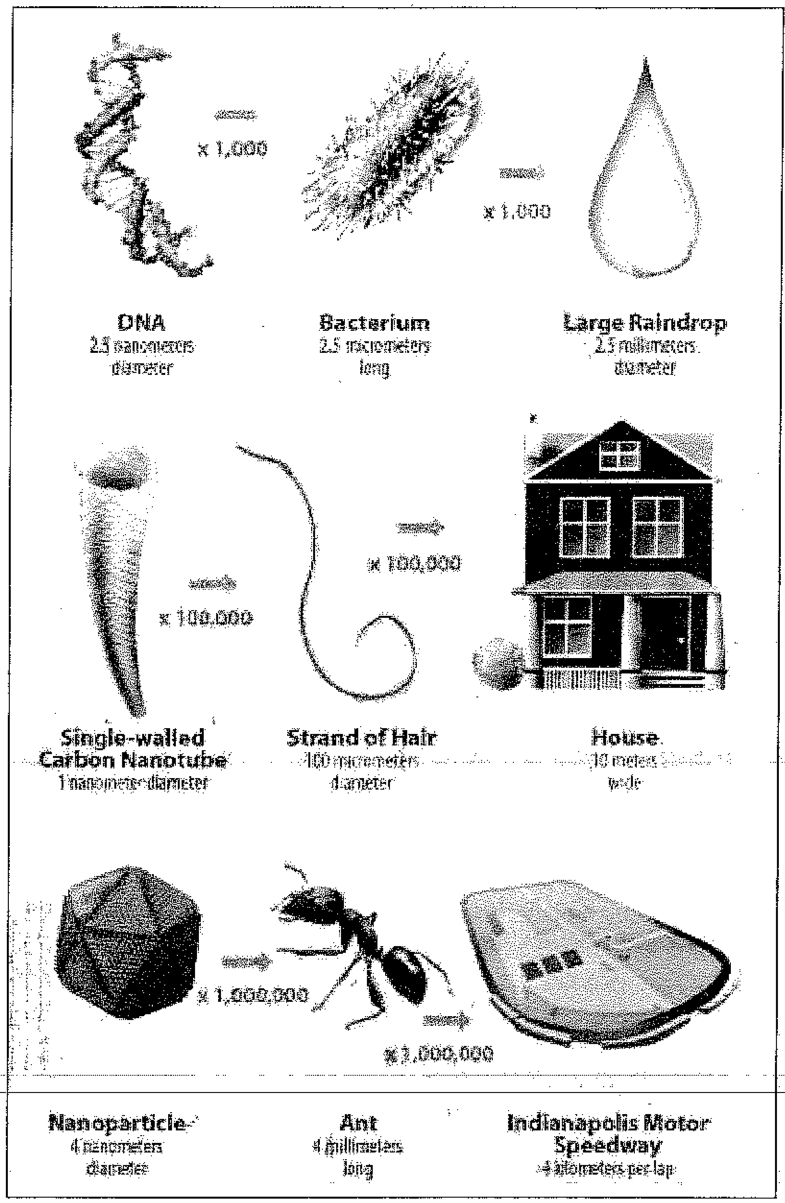

Figure1. The Scale of Nanotechnology (Used with permission. Courtesy of the National Center for Electron Microscopy, Berkeley, CA., US Department of Energy.)

Some brands of sunscreens, tennis balls and CDs contain nanoscale materials. The application of nanomachines for site-specific delivery of drugs in the targeted chemotherapy of cancer cells and the application of medical nanomachines to manipulate cellular structures in genetic engineering are some of the outstanding advancements in man-made developments in the biological applications of nanoscale science[4,5]. In addition to man-made developments, there are amazing nanoscale applications found in nature. For example, an understanding of the F1-ATPase molecular motors of 10 nanometers across that are found in the abalone mollusk has enabled scientists to envision and develop nanoscale motors. This is an exciting example of nanotechnology interwoven with the biological world. In the context of man-made and natural nanoscale applications, the integration of nanoscale science and technology into college biological science education is worth exploring.

RELEVANCE

If college students are to know current trends in science, they must understand the basic concepts and applications of nanoscale science and technology. Nanoscale science and technology adds "a new excitement to many subjects. Students see amazing applications that result from nanoscience, and learn that an understanding of basic science is necessary to make them happen. For example, CD's wouldn't exist without nanotechnology; neither would the new color changing paints on luxury cars and motorbikes; transparent sunscreens and many new cosmetics use nanoparticles; the technology behind stay-clean chinos and even new school uniforms is nanotechnology. These developments depend on a fundamental knowledge of chemistry, physics and biology." (Ref. 6). The widespread use of nanoscale materials in real life products, and the exciting counter-intuitive science of the nano-world undergird compelling reasons and provide a rationale for incorporating nanotechnology into biological science education[7,8].

The 2003 enactment of the 21st Century Nanotechnology Research and Development Act by the United States Congress as well as sustained budgetary investment in the National Nanotechnology Initiative (NNI) since its establishment in 2001 are definite indicators of a high level of federal awareness that advances in nanotechnology research and education are extremely important for future success of the United States. It is clear that nanoscience education of students will accelerate advances in medicine, manufacturing, information technology, and development of a sustainable environment. Additionally, college faculty members must embrace challenges or obstacles and work assiduously with other educators to ensure that America can provide the workforce required for future scientific and technological advances[9,10].

INTEGRATION

Successful integration of nanoscience and nanotechnology into college biological science is a challenging task that will require modification of the college science curriculum. According to Rocco[11], the convergence of nanoscale science with modern biology and medicine is a trend that should be reflected in science curriculum policy decisions. In the case of biology, there is no clear blueprint for designing a college level biological science course addressing nanoscience and nanotechnology concepts. When designing or redesigning a college level science course, it is important for selected topics to fall within the college's science curriculum. Additionally, the objectives must be reasonable and measurable, and the pedagogy must be based on established learning theories.

In the context of integrating nanoscience into a biological science course, curriculum and instruction decisions must be rationalized by how this new science contributes to student learning and helps to advance science[12,7,13]. Bearing these parameters in mind, the following topics, behavioral objectives and related pedagogical strategies are proposed for the integration of nanoscale science and technology into a general biology course for both majors as well as non-science majors.

1. Introduction to nanoscience and nanotechnology
2. Nanometrics
3. Nanoscale Materials and Structures
4. Microscopy
5. Nanoscale Materials of Life
6. Cell Study
7. Protein Synthesis

Each of the above topics is accompanied by specific objectives as well as prescribed pedagogical and assessment strategies in the following section. Table 1 presents an outline of how the above topics may be organized in terms of selected content, pedagogical strategies, biological examples, assessment strategies, and a tentative time frame for integrating nanoscale science and technology into college biology curricula.

TOPICS, OBJECTIVES, AND PEDAGOGICAL STRATEGIES

Topic 1: Introduction to Nanoscience and Nanotechnology

- Nanoscale
- Nanoscience
- Nanotechnology
- Nanobiotechnology
- Applications in everyday life

Objectives

Upon completion of the topic, students will be able to perform the following tasks:

i) Demonstrate knowledge that one nanometer is a billionth of a meter.
ii) Define 'Nanoscience' as the study of phenomena and manipulation of materials at atomic, molecular, and macromolecular scales.
iii) Define 'Nanotechnology' as the study and design of systems at the nanometer scale (the scale of atoms and molecules).
iv) Describe 'Nanotechnology' as being "bottom up" because nanomaterials are produced as a result of the assembly of molecules and atoms.
v) Define 'Nanobiotechnology' as technology concerned with materials and systems whose structures exhibit improved physical, chemical and biological properties in living organisms due to their nanoscale size[14].
vi) Demonstrate awareness of the extreme smallness and invisibility of the nanoscale to the naked eye.
vii) Discuss implications of nanoscience and nanotechnology for the manufacture of nanostructures with multiple functions including disease diagnostics as well as garment and medical care.

Pedagogical Strategies

Pedagogical strategies involve the following activities:

i) Topic introduction: The teacher will introduce the topic and students will view a video clip highlighting societal implications of nanoscience and nanotechnology. The video will serve as an advance organizer that will provide students with basic information for constructing knowledge and learning new concepts in a meaningful manner.
ii) Discussion of introductory video: The teacher will utilize skilled questioning and serve as an effective moderator during a classroom discussion of the video.
iii) Brain-storming: The teacher will guide students to formulate their own definitions of the terms nanotechnology, nanobiotechnology, nanoscience, and nanoscale.
iv) Internet research project: Students will work in groups of three (3) as they use Internet search engines such as Google and Yahoo to garner information for preparing poster or PowerPoint presentations on specific topics related to "Nanotechnology", "Nanobiotechnology", or "Nanoscience".
v) Group presentations: Students will present group projects on Nanotechnology", "Nanobiotechnology", or "Nanoscience" to the entire class.

Assessment: The learning process will be assessed based on the following criteria:

i) Responses to questions asked by the teacher and peers
ii) Engagement in the research process
iii) Students' participation and performance in their project and presentation. An appropriate rubric will be used to assess each project and presentation.

Topic 2: Nanometrics

- The metric system
- Powers of ten
- Linear metric conversions
- Micrometer vs. nanometer
- Measurements

Objectives

Upon completion of the topic, students will be able to perform the following tasks:

i) Demonstrate knowledge that the standard metric unit of length is the meter (m).

ii) Explain that the metric system is based on units of ten (10).
iii) Name fractions and multiples of a meter as well as the appropriate prefix and symbol used to denote each fraction or multiple.
iv) Demonstrate awareness of the existence of structures with dimensions at the micrometer and nanometer level in real life contexts.
v) Explain that a nanometer is 80,000 times smaller than the width of a strand of human hair.
vi) Explore the Powers of Ten Website at www.powersof10.com and compare the relative size of selected objects such as the earth (100,000,000 m), Lake Michigan (1,000,000 m), a small park (100 m), a white blood cell (0.00001 m), and a DNA molecule (0.00000001 m).
vii) Measure the length and width of an object.
viii) Convert large linear metric units into smaller ones as a result of multiplying by an appropriate factor of ten (10).
ix) Convert small linear metric units into larger ones by means of dividing by an appropriate factor of ten (10).

Pedagogical Strategies

Pedagogical strategies involve the following activities:

i) Linear measurements: Students will use metric rulers to measure and record the length and width of objects that vary in size from one meter to one millimeter.
ii) Linear conversions: Students will convert large linear units into smaller ones and small units into larger ones.
iii) Poster research project: Students will work in groups of four (4) to prepare and present posters that compare objects at the macroscale, the microscale, and the nanoscale.

Assessment: A checklist based on the following criteria will facilitate the assessment of each student's learning:

i) Relevance and type of questions asked by students
ii) Appropriate use of metric rulers
iii) Accuracy of metric conversions
iv) Student participation and performance in the poster presentations

<u>Topic 3: Nanoscale Materials and Structures</u>

- Nanocomposites
- Benefits/Uses
- Applications in everyday life
- Safety issues

Objectives

Upon completion of the topic, students will be able to:

i) Define nanomaterials as materials with grains, particles, fibers, or other constituent components that have one dimension less than 100 nm[15].
ii) Demonstrate knowledge that medical devices such as self-adjusting braces, health products like sunscreen lotions contain nanomaterials.
iii) Explain that work at the nanometer level can provide ways of improving the performance of products such as medical devices, drug delivery in site-specific chemotherapy, and long-life batteries used in implantable cardiac defibrillators.

Pedagogical Strategies

Pedagogical strategies involve the following activities:

i) Video presentation on nanomaterials, their uses, and safety issues: Students will observe a video in which nanostructures are featured. The video will provide students with educationally rich and authentic macrocontextual environments in which instruction of nanoscience and nanotechnology are anchored[16,7,17]. The video will expose students to environments for cooperative learning and teacher-directed mediation. Additionally, students will be provided with opportunities to identify problems, recognize clues, and engage in meaningful learning.
ii) Internet research project: Students will use the Internet and work in groups of three (3)

to research and garner information for preparing a portfolio on nanomaterials, their uses, and safety issues.

Assessment: Students' learning will be assessed based on the following criteria:

i) Ability to identify problems and recognize clues that are related to the use of nanomaterials
ii) Accuracy of information included in portfolios

Topic 4: Microscopy

- Scanning probe microscope (STM)
- Atomic force microscope (AFM)
- Force-modulated microscope (AFM)
- Lateral force microscope (LFM)
- Magnetic force microscope (MFM)
- Scanning thermal microscope (Stem)
- Electrical force microscope (EFM)
- Near-field scanning optical microscope (NSOM)

Note: Students will use scanning probe and atomic force microscopes in a nanoscience virtual laboratory.

Objectives

Upon completion of the topic, students will be able to perform the following tasks:

i) Describe scanning probe microscopes as a family of related instruments that include the Scanning probe microscope (STM); Atomic force microscope (AFM); Force-modulated microscope (AFM); Lateral force microscope (LFM); Magnetic force microscope (MFM); Scanning thermal microscope (Stem); Electrical force microscope (EFM); and Near-field scanning optical microscope (NSOM).
ii) Identify and use virtual scanning probe and atomic force microscopes to view biological samples.
iii) Demonstrate knowledge of the structure and function of different parts of scanning probe and atomic force microscopes.

Pedagogical Strategies

Pedagogical strategies involve the following activities:

i) Observation and identification of the parts of a scanning probe microscope (STM) and an atomic force microscope (AFM): Students will observe a STM and an AFM in a virtual nanoscience laboratory. Later, groups of four (4) students will refer to labeled pictures of each type of instrument and work collaboratively to identify the parts of the microscopes.
ii) Video presentation on structure and function of scanning probe and atomic force microscopes: Students will observe and discuss a video with anchored instruction on the structure and function of scanning probe and atomic force microscopes.
iii) Use of virtual scanning probe and atomic force microscopes to view biological samples.

Assessment: Learning among groups of students will be assessed based on the following criteria:

i) Identification of parts of the scanning probe and atomic force microscope
ii) Ability to use virtual scanning probe and atomic force microscopes for viewing biological samples

Topic 5: Nanoscale Materials of Life

- The range of chemicals in living organisms
- DNA, RNA, and protein detection
- DNA vs. RNA structure and function
- Protein structure and function

Objectives

Upon completion of the topic, students will be able to perform the following tasks:

i) Demonstrate knowledge of the structure and functions of different types of molecules in a living organism.
ii) Use probes on virtual scanning probe and atomic force microscopes to image and identify biological molecules such as DNA, RNA, and proteins.
iii) Use biosensors for detection of proteins, RNA, and DNA molecules in cells.

Pedagogical Strategies

Pedagogical strategies involve the following activities:
i) Video presentation of chemicals in living organisms: Students will observe a video-based instruction on imaging, detection, structure, and functions of chemicals in living organisms.
ii) Using scanning probe and atomic force microscopes for imaging biological molecules: Students will use virtual scanning probe and atomic force microscopes on the Internet to form images of DNA, RNA, and protein molecules. This objective is intended to engage students in hands-on processes while they study the structure of the nanoscale materials.
iii) Modeling: Students will use modeling kits to build models of DNA, RNA, and protein molecules.

Assessment: Students' learning will be assessed based on the following criteria:
i) Engagement in the hands-on learning processes
ii) The type and relevance of questions asked
iii) Ability to use kits for building models of DNA, RNA, and protein molecules.

<u>Topic 6: Cell Study</u>
- Cell anatomy
- Cellular functions
- Use of microscopic probes
- Measurement of cellular structures

Objectives

Upon completion of the topic, students will be able to perform the following tasks:
i) Distinguish between prokaryotic and eukaryotic cells.
ii) Identify parts of a plant and an animal cell.
iii) Explain functions of different cellular components.
iv) Use probes on a scanning probe microscope and an atomic force microscope for measuring biological samples. This objective is intended to engage students in the hands-on process of measuring nanoscale cellular structures.
v) Demonstrate awareness of the extreme smallness and invisibility of cellular structures to the unaided eye.

Pedagogical Strategies

Pedagogical strategies involve the following activities:
i) Observation of cellular structures: Students will use a scanning probe microscope and an atomic force microscope for observing structures in plant and animal cells.
ii) Measurement of biological samples: Students will use a scanning probe microscope and an atomic force microscope for obtaining measurements of structures in or on biological samples.
iii) Research project: Students will use the Internet or any other resource and work in pairs to research and garner information for preparing a highly illustrated portfolio on the functions of cellular components.

Assessment: Pairs of students will be assessed based on the following criteria:
i) Ability to use the scanning probe and atomic force microscopes
ii) Accuracy of information included in their portfolios

<u>Topic 7: Protein Synthesis</u>
- The genetic code
- DNA and RNA functions
- Events of protein synthesis

Objectives

Upon completion of the topic, students will be able to perform the following tasks:
i) Explain the genetic code.
ii) Contrast the function of DNA with the function of specific types of RNA molecules.
iii) Describe the sequence of events that occur during protein synthesis.

Pedagogical Strategies

Pedagogical strategies involve the following activities:
i) Research project: Students will use the

Internet and work in groups of five (5) to research protein synthesis and prepare short PowerPoint presentations on the topic.

ii) Panel discussions: Students will engage in highly structured panel discussions about events that occur during protein synthesis. One member of each group of five students will be the moderator and the other four will be panelists/discussants.

Assessment: Learning among groups of students will be assessed based on the following criteria:

i) Engagement in the research process
ii) Accuracy of information included in PowerPoint presentations
iii) Quality of performance in panel discussions

The integration of this proposed program of instruction will require time commitment in typical lecture or laboratory class periods. Tentative times shown in Table 1 are intended to facilitate the integration of nanoscience and technology topics into various aspects of a college biology course.

DISCUSSION

Any attempt to incorporate nanoscience into biological science course offerings at the college level will be faced with issues related to curriculum, instruction, and assessment of the learning process. Specific obstacles that must be anticipated and strategically overcome are financial constraints, resistance of administrators and faculty members to curriculum change, a lack of appropriate laboratory instrumentation to support instruction, and a lack of expertise among stakeholders to implement change. Selection and sequencing of content, implementation of pedagogical and motivational strategies, as well as evaluation of the academic achievement of students are a few of the challenges associated with the integration of nanoscience and nanotechnology into college biology.

Curriculum issues

Content selection from the vast nanoscience and technology knowledge base is a major curriculum issue for biological science faculty members who are innovative enough to design biology courses with a nanoscience flavor. Advances in nanoscientific and nanotechnological research and discoveries are occurring at such a fast rate that science education reform has the potential to accelerate at rates that may overburden effective curriculum decision-makers.

Nanoscience and nanotechnology literature reflect a rapidly increasing interest in nanoscience and nanotechnology research that has caused new nano-knowledge to be constantly supplanting previous knowledge. This exasperates the recurring problem of content coverage faced by teachers. Curriculum decision makers who accept the challenge of incorporating nanotechnology into any college level science program must ask the question that was asked by Herbert Spencer in 1859. "What knowledge is of most worth?" This question is possibly more relevant in 2010 than it was in 1859. Hence, content selection for nanoscience and technology education can become a controversial curriculum issue.

Additional curriculum issues that are directly related to content selection for the incorporation of nanotechnology into college biological courses include appropriate sequencing of subject matter and integration of new knowledge into existing curricula. It is necessary for subject matter to be sequenced in a manner that is meaningful to the diverse spectrum of learners who are usually under prepared for college science education. Likewise, it is imperative that integration of new knowledge into existing curricula be done in a manner that will facilitate coherent presentations and foster learner understanding.

Instructional issues

Development and implementation of teaching strategies that challenge, but do not frustrate, students must be a primary pedagogical goal for educators. This is deemed to be important if students are to experience academic integration

Table 1. Selected Content, Pedagogical Strategies, Biological Examples, Assessment Methods, and Tentative Time Frames for integrating Nanoscale Science and Technology into College Biology Curricula

Content	Pedagogical Strategies	Biological Examples	Assessment Methods	Tentative Time
Introduction to nanoscience and nanotechnology	Video presentation and discussion: Nanoscience and Nanotechnology (advance organizer employed by teachers to relate new information to students' pre-existing knowledge)		Group PowerPoint presentations	1 hour
Nanometrics	Scientific inquiry: Exploration of the Powers of Ten Website; comparison of the relative size of selected objects; linear measurements and metric unit conversions; poster research project	White blood cells DNA	Group poster presentations	3 hours
Nanoscale Materials and Structures	Scientific inquiry: video presentation - Nanomaterials, their uses, and safety issues Internet research project and compilation of portfolio on nanomaterials		Portfolios	6 hours
Microscopy	Scientific inquiry: study of scanning probe and atomic force microscopes via diagrams and video presentation; use of scanning probe and atomic force microscopes to view biological samples	DNA RNA Protein	Use of scanning probe and atomic force microscopes	6 hours
Nanoscale Materials of Life	Scientific inquiry: video presentation - Chemicals in living organisms Scanning probe and atomic force microscopy imaging and modeling of selected biological molecules	DNA RNA Protein	Model building	6 hours
Cell Study	Scientific inquiry: observation of cellular structures; measurement of biological samples; research project; compilation portfolio on functions of cellular components	Bacteria Plant cells Animal cells	Portfolios	8 hours
Protein Synthesis	Scientific inquiry: research project PowerPoint presentations; panel discussions	DNA RNA Protein Ribosomes	PowerPoint presentations and panel discussions	8 hours

into communities of educational institutions that cause them to persist from one semester to the next until they complete their specific programs of studies. Tinto[18], in a research on student retention, noticed that poor integration of students into academic communities of colleges is one of the reasons for students' decisions to dropout of colleges.

Kumar[19], in a study of nanoscale science and technology in teaching among undergraduate science education students noticed that the etymology of scientific and technological terms and the physical scale of nanoscience and nanotechnology are areas needing special attention. College students and especially those gearing towards science teaching careers must be provided "indepth opportunities to discuss and develop cognitively engaging and motivating ways of teaching nanoscale science and technology. Particular attention must be paid to the etymology of science and technology terms and the physical scale upon which the field of nanoscience and nanotechnology is developed" (p. 21).

Other pertinent curriculum issues are education and professional development of faculty members; selection and provision of instructional resources; development of courses; and implementation of appropriate teaching strategies. These are also glaring instructional issues that must be addressed if the incorporation of nanoscience and nanotechnology into college biological science programs are to be effectively achieved. Most colleges lack scanning probe microscopes and other basic pieces of equipment that are required for engaging students in meaningful hands-on nanoscience experiences.

The selection and provision of laboratory equipment and other instructional resources such as textbooks, and computer-software are additional challenges that must be overcome before nanoscience can be effectively incorporated into college biological science curricula. Education and professional development of full-time as well as adjunct biological science faculty members must be done to enable individuals to cope with the challenges of effectively educating students in a rapidly changing nano-world. Nanoscience and technology are relatively new and interdisciplinary; hence many biological science teachers need professional development to empower them and to eliminate feelings of inadequacy.

Assessment Issues

Based on Douglas Huffman's recommendation[20], assessment of learning associated with the integration of nanoscale science and technology into college biology should employ multiple formats and be closely aligned with instruction. This statement implies that assessment strategies should mirror or clearly reflect the instructional objectives. Specifically, there should be provisions in any nanometric course for assessing student performance in both lecture and laboratory contexts. It is important to note that both lecture and the corequiste laboratory components of the course need to complement each other. Laboratory components of a nanometric course should expand learning and understanding of concepts that are taught in the lecture classes.

This article presents a variety of strategies that can be used for summative and/or formative assessment of teaching as well as learning of nanoscale science and technology. The proposed summative assessment strategies can be used to determine students' final grades for the course. This proposal is based on Sally Brown's claim[21] that summative assessment can enable judgements to be made about students' progression and completion. In contrast to summative assessment, formative assessment can be used to elicit meaningful feedback from teachers and students for initiating improvement in both the teaching and learning processes.

Most of the assessment strategies outlined in this article are formative and are based on the notion that formative assessment should help students to learn. Hence, feedback about the efficacy of teaching and learning must be the hallmark of formative assessment. However, teachers need to be aware of the positive or negative impact that feedback may have on students' motivation to learn. This statement implies that teachers need to be tactful and accept the challenge of providing students with honest, meaningful feedback about learning.

ENDNOTE

Colleges must accept the responsibility of ensuring that their graduates can effectively contribute to the global workforce necessary to make economic strides, and scientific and technological advances in the life sciences. Integrating nanoscale science and technology into college biology courses is a promising way to prepare scientifically and technologically well-informed graduates. Resolving important curriculum and instruction issues are critical to ensuring that college students gain meaningful knowledge of nanoscale concepts related to biology. Advancing college biology in this 21st century needs a shift in curriculum and instruction from macroscale to nanoscale.

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The *Scale of Nanotechnology.* Used with permission. Courtesy of the National Center for Electron Microscopy, Berkeley, CA., US Department of Energy.

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