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Development of an Integrated Curriculum for Educating Engineers about Nanotechnology: End-of-Life Management of Nanomaterial-Containing Wastes

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Introduction

The rapid development of the nanotechnology field and its prevalence in our daily lives necessitates undergraduate engineering students be prepared to enter a workforce where references to and uses of nanotechnology will likely be commonplace. Students not only need to be well-versed in the fundamental aspects of nanotechnology, but also need to understand the impact and implications of nanotechnology in their respective fields. An area important for civil and environmental engineering (CEE) students to gain exposure is the environmental implications of nanomaterial use in products/materials and subsequent end-of-life management. Nanomaterial incorporation within consumer products, construction materials, and other medical or electronic devices is steadily increasing, necessitating future engineers be educated to develop environmentally sound end-of-life management strategies for these nanomaterial-laden items.

Development of an appropriate end-of-life management strategy for these materials/wastes requires integration of the fields of nanotechnology, waste management, and environmental engineering. The synergy between these areas presents an excellent opportunity to provide students with an interrelated educational experience. This paper describes the early stages of the development and implementation of an integrated undergraduate nanotechnology theme within the current CEE curriculum at the University of South Carolina. This integrated approach is referred to as a Nanotechnology LINK, or Learning Integration of New Knowledge. The curriculum theme focuses on the environmental implications associated with the end-of-life management of nanomaterial-containing products, materials, and nanomaterial manufacturing waste streams. A major component of this integrated curriculum is the development of a network of nanotechnology problem-based, hands-on learning modules using a pedagogical approach referred to as Environments for Fostering Effective Critical Thinking (EFFECTs). These modules are being developed for use throughout the CEE curriculum in freshman, junior, and senior level courses. The EFFECTs are geared towards introducing students to important aspects of nanotechnology fundamentals (e.g., surface area, surface chemistry), as well as potential issues associated with nanomaterial disposal (e.g., transport in waste environments, health concerns).

Background

Approaches to undergraduate nanotechnology education

There have been worldwide efforts to insert nanotechnology education in the undergraduate engineering curriculum, ranging from single courses on nanotechnology to nanoengineering tracks within a curriculum.[1,2] Full-scale academic undergraduate programs in nanotechnology engineering have also been created.[3] To ensure institutionalization of nanotechnology education, Crone et al.[4] promote the incorporation of nanotechnology concepts through the use of well-designed educational modules into established engineering and science courses that are integral components of the engineering curriculum and will impact a broad cross-section of students.

Furthermore, the integration of nanotechnology content must be consistent with the course objectives and outcomes to avoid random interjection of new material that is not sustainable for teaching and learning.[4] This means that a thoughtful process for course and content mapping within a given curriculum must be applied.

Undergraduate students have variable levels of awareness of nanotechnology and motivation to learn more about this complex subject.[5] While many students are interested in nanotechnology, one of the significant challenges is with understanding concepts like size and scale. To overcome these conceptual limitations, nanotechnology should be taught in a manner that couples knowledge-centered environments with student-centered learning to stimulate higher order cognitive skills. Given that nanotechnology developments occur at a rapid pace, educational activities that provide opportunities for creative and critical thinking should be prioritized throughout the learning process to enhance student understanding.[2,6] Hands-on learning that exposes students to nanotechnology tools and methods in appropriate lecture-based and lab courses is also critical.[6] For example, Zheng et al.[7] used problem based learning (PBL) strategies for infusing nanotechnology in a course on construction materials to stimulate creativity and self-regulated learning of civil engineering students in that course. Like many courses with nanotechnology content, this course focused solely on nanomaterial applications (e.g. to improve construction material performance and structural health monitoring of civil infrastructure through the use of smart nanocomposites and innovative design of intelligent structures). Chopra and Reddy[6] advocate for the inclusion of topics related to safe handling, disposal, and storage of nanomaterials, which have tremendous societal impacts given that the environmental and health effects are uncertain and still being studied.[8-10]

Environments for Fostering Effective Critical Thinking (EFFECTs)

EFFECTs are modular inquiry based tools specifically designed to develop critical thinking skills and collaborative teamwork skills while improving the transfer of core knowledge in science, technology, engineering and math (STEM) courses. The EFFECT framework is presented in Figure 1. EFFECTs are based on a driving question where students consider fundamental concepts in the context of a realistic problem. In the first EFFECT session (class period), students complete a decision worksheet, individually and then in groups, and provide an initial answer to the driving question. This first session is followed with multiple active learning sessions that are designed to enhance the student's core knowledge, stimulate critical thinking, and hone their estimation abilities. Active learning modules integrate hands-on and minds-on experiences. At the

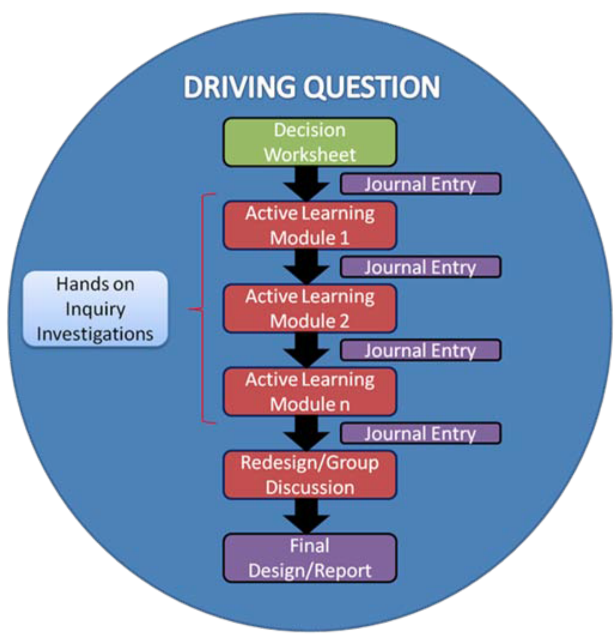


Figure 1. The EFFECT framework.

conclusion of each active learning session, students reflect on their learning by responding to questions in an online journal system developed for this purpose, called the Online Assessment Tool (OAT). Instructors rate student responses using a rubric designed to assess both core knowledge and critical thinking. Written feedback is provided within OAT to explain the ratings and identify student misconceptions or misunderstandings. Each EFFECT concludes with a student report that contains a final answer to the driving question, which is supported with the proposed solution and how the solution has changed as a result of the active learning exercises. These EFFECTs have been shown to measurably improve the critical thinking and scientific reasoning skills of civil engineering students.[11]

Development of the Nanotechnology LINK

Work is currently being conducted to expand the EFFECT framework to provide students with a learning experience that spans a sequence of courses in the CEE curriculum. EFFECT activities are being developed for use in individual courses and are subsequently linked to one another to form the Nanotechnology LINK (a network of EFFECTs with a central theme), as illustrated in Figure 2. These activities will align with content currently taught in each course, but will focus on the environmental implications associated with the end-of-life management of nanomaterial-containing products, materials, and nanomaterial manufacturing waste streams. In other words, the addition of these problem-based modules does not necessarily replace material covered in each course; rather, the modules create a nanotechnology-specific context that provides students with opportunities to apply learned concepts. Nanotechnology concepts that are expected to be covered in each EFFECT are listed in Table 1. EFFECTs for the listed courses are in different stages of development; activities completed to date in three courses are described below.

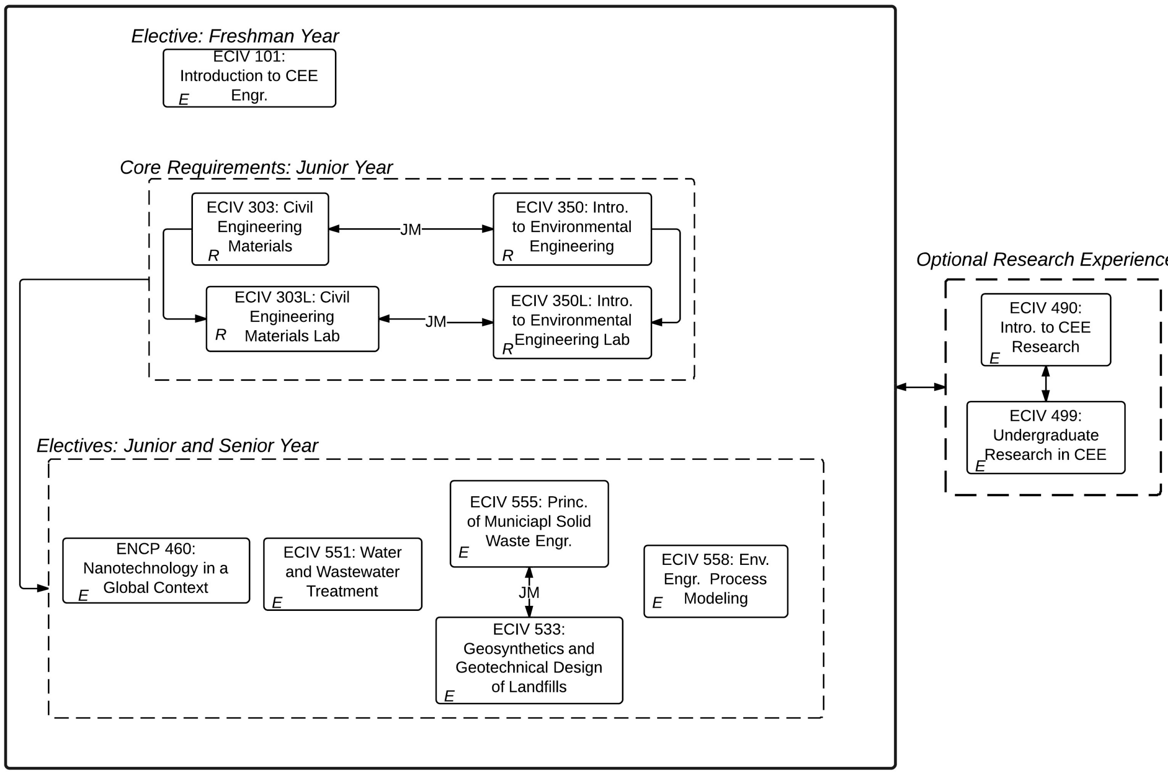
ECIV 101: Introduction to Civil and Environmental Engineering

The first student exposure to nanotechnology occurs in Introduction to Civil and Environmental Engineering (ECIV 101). It should be noted that ECIV 101 is an elective course in the current CEE curriculum. Starting in Fall 2015, this course will be required for incoming freshmen who have declared CEE as a major.

In Fall 2013, an EFFECT introducing students to surface area at the nanoscale was implemented in this course. Students were asked to determine the mass of carbon nanotubes required to remove natural organic matter (NOM) from water sources and to compare NOM removal achieved with nanomaterials to that obtained when using activated carbon (a more common adsorbent). To accomplish this, students conducted batch adsorption experiments. Their experimental results highlighted the increased surface area associated with nanomaterials and provided sufficient information for students to estimate the mass of carbon nanotubes and activated carbon required to remove NOM from a water source for a small community.

ECIV 303: Civil Engineering Materials

All undergraduate students are exposed to nanotechnology during their junior year when they enroll in their core CEE courses, which includes ECIV 303: Civil Engineering Materials and ECIV 350: Introduction to Environmental Engineering. At this point in the CEE curriculum, students have completed lower division requirements in science and math (e.g., chemistry, physics, calculus) and completed fundamental engineering courses (e.g., statics, mechanics of solids). Students may also have taken ECIV 101.



R = required course
E = Elective
JM = joint modules will be developed/implemented

Figure 2. Flowchart depicting the courses in which nanotechnology modules will be incorporated.

In Fall 2013, a group of students in ECIV 303 researched the incorporation of nanomaterials in cement composites for their course project. This was done, in part, to identify core concepts for the development of an EFFECT that will be implemented in Fall 2014. Students reported to the class on several nanotechnology-related concepts, such as how nanomaterials are incorporated within these materials, how they improve/modify material properties, and potential end-of-life disposal issues. All of these topics/concepts align well with the material currently covered in ECIV 303.

ECIV 555: Principles of Municipal Solid Waste Engineering

In Spring 2014, an EFFECT was developed and implemented to introduce students to the number of nanomaterial-containing consumer products currently on the market and provide them with an awareness of their growing presence in municipal solid waste landfills. After providing students with the context of being an Imagineer at Walt Disney World in Orlando, Florida and being confronted with the disposal of nano-TiO_2 containing consumer products, they were asked to answer the driving question: What concentration of nano-TiO_2 would you expect to find in leachate from waste originating from Walt Disney World Parks and Resorts? Students worked in groups and combined their knowledge of municipal solid waste and landfill operations gained from this course with information they discovered when using the findNano app (developed by The Project on Emerging Nanotechnologies).

Table 1. EFFECTs Currently Being Developed for the Impacted Courses.

Course Number and Title	Topics of EFFECTS being Developed
ECIV 101: Intro. to Civil and Env. Engr.	❖ Introduction to nanotechnology and role of nanoparticles in environmental engineering through water/wastewater treatment and groundwater remediation
ECIV 303: Civil Engr. Materials	❖ Introduction of nanomaterials to construction materials ❖ Influence of nanomaterial addition on construction material properties
ECIV 303L: Civil Engr. Materials Lab	❖ Characterization of nanomaterials as well as nanomodified materials using nanoimaging
ECIV 350: Intro to Env. Engr.	❖ Toxicity when using nanoparticles and related risks with handling during manufacturing and construction
ECIV 350L: Intro to Env. Engr. Lab	❖ Potential for using nanomaterials for water/wastewater treatment
ENCP 460: Nanotechnology in a Global Context	EFFECT modules already being conducted, including examples with: Introduction and general physics, chemistry, and biology at the nanoscale; arsenic remediation
ECIV 533: Geosyn. and Geotech. Design of Landfills	❖ Interaction between discarded nanomaterials and landfill liners and resulting impacts on barrier longevity
ECIV 551: Water and Wastewater Treatment	❖ Fate of nanomaterials in wastewater treatment ❖ Nanomaterials for contaminant removal
ECIV 555: Principles of MSW Engr.	❖ Fate of nanomaterials in landfills (e.g., nanomaterial origin and transport) ❖ Life-cycle assessment of nanomaterial-containing product disposal
ECIV 558: Env. Process Modeling	❖ Prediction of nanomaterial transport ❖ Calculation of interaction energies of nanomaterials and contaminants and/or waste materials using molecular modeling

Future Work

Future work activities include the continued development of instructional videos, linked EFFECTs, and assessment tools for integrated learning.

Educational video modules providing students with a fundamental background on nanomaterials are being developed. These videos will provide answers to the following questions: What are nanomaterials? What do nanomaterials look like? Where are nanomaterials used? Why are nanomaterials used? What concentration of nanomaterials is found in products? How are nanomaterials integrated in products? How do we discard nanomaterial waste? Students will be required to view these video modules as part of ECIV 303 and 350. These educational videos are also intended to serve as reference sources for the integrated curriculum theme, and so students will have continued access to the videos beyond these two courses.
Joint EFFECT modules for ECIV 303 and 350 and ECIV 533 and 555 (Figure 2) are currently being developed. It is expected that these joint modules will provide continuity to students and

enhance their learning experience. For example, a common context will be developed for active learning modules in ECIV 303 and 350 as well as the associated lab courses (ECIV 303L and 350L). EFFECTs will be implemented in all four courses in Fall 2014.

Student construction of nanotechnology-based concept maps will be used to facilitate linking of the EFFECTs. Concept maps, along with end products from each EFFECT, will be assembled to produce nanotechnology-themed electronic portfolios or blogs. The e-portfolio content for students will expand as they advance through the sequence of impacted courses, with concept maps being revisited and revised in each impacted course. Assessment of content knowledge through student-generated concept maps has been trial tested independently in ECIV 101 and 555. Preliminary findings from each course indicate that concept maps are useful tools for students to illustrate their understanding of nanotechnology concepts. Future work includes the development of assessment techniques to evaluate how students integrate learning through a series of concept maps across the curriculum.

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