Emphasizing Environmental Health and Safety Training in all Aspects of the Emerging Nanotechnology Field

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Abstract:

Progress in engineering and the life sciences, including nanotechnology and high-throughput experimentation, offers an opportunity for understanding material science, biology and medicine from a systems perspective. In this paper, we propose new safety system teaching approaches in the emerging nanotechnology field of study. They focused on the departure from the traditional instructional models without fully discarding them. The educational objectives are to expose students to the open-endedness nature of professional engineering discourses, to appreciate the interconnectedness of knowledge disciplines and the multidisciplinary nature of professional engineering practices, and to instill into students with skills and knowledge which are convergent with the higher levels of Bloom's taxonomy. This "*new view*", which complements the more traditional component-based approach, involves the integration of biological research with approaches from engineering disciplines and computer science. The method results in more than a new set of risk assessment technologies. Rather, it promises a fundamental reconceptualization of the environmental health and safety training based on the development of quantitative and predictive models to describe crucial processes. To achieve this change in safety culture, learning communities (International Curriculum on Nanotechnology) are being formed at the interface of biology systems, engineering and computer science. Through this new teaching/learning communities, research and education can be integrated across disciplines and the challenges associated with multidisciplinary team-based science and engineering can be addressed. The results show a general positive relationship between the use the learning technology and student engagement and learning outcomes.

Keywords: Engineering education, Nanotechnology, System safety, Multidisciplinary teaching

1. Introduction

From macroscopic perspectives, the emerging field of nanotechnology represents an integration of concepts and ideas from the life sciences, systems biology, engineering disciplines and computer science. Recent advances in nanotechnology, including biotechnology and massively parallel approaches to probing biological samples, have created new opportunities for understanding engineering and biological problems from a systems perspective. Systems safety becomes a key component that supports the development of this new technology. For this new technology in embryonic development, system safety led the perspective to regard the potential of collaborative learning and cooperative learning as strong instructional strategies. Hattie's (2009), [4], more recent meta-analyses point to a number of critical conditions that are needed to attain a positive impact of collaboration. Johnson and Johnson (1996), [6], cite certain guidelines that must be met to support collaboration: guarantee individual accountability, assure group accountability, develop communication skills, make sure that shared objectives are pursued, and break down complex group tasks.

Nanotechnology-based products have emerged as the most commercially viable products of this century because of their wide-ranging utility in our daily lives. These products have the potential to affect the health and safety of the industrial workforce and the general public. Nanostructured materials such as nanotubes, fullerenes, nanopowders, dendrimers, nanoparticles, nanocrystals, and nanocomposites are globally produced in large quantities due to their wide potential applications (e.g., in skincare and consumer products, photonics, healthcare, biotechnology, pharmaceuticals, and drug delivery), [10], [12], [13]. However, the environmental, health, and safety uncertainties posed by these products need to be characterized, due to the fragmentary scientific knowledge of their health and safety risks. With classical engineering training and design, often, systems are designed and then an attempt is made to add safety features or to prove that the design is safe after the fact, or to detect accident causes after catastrophic events.

The proposed approach in system safety training emphasizes the functional behavior of collections of components working together and builds upon the more traditional approach of studying the individual roles of single components. Systems modeling and design are well-established in engineering disciplines but, until recently, have been relatively rare in biology. To explore the application of complex systems analysis to nanotechnology and public safety concerns, multidisciplinary teams of biologists, engineers and computer scientists are working together – applying principles and techniques from engineering with concepts and algorithms from computer science to solve problems in nanotechnology safety and medicine.

Building on the international curriculum on nanotechnology to support communication, collaborative learning has also become an integral part of learning management systems. From systems safety perspective, the integration of the international curriculum has brought about a new strand of educational research focusing on public safety, computer conferencing, biology systems, computer-mediated communication, also resulting in an established research field known as computer supported collaborative learning, a new area in engineering learning and teaching. In addition, Henri (1992), [5], introduced quantitative approaches (such as the number of messages, level of interaction) and qualitative approaches (such as surface or deep level processing) to study the impact of collaboration in these online learning environments, Pena-Shaff and Nicholls, (2004), [11].

To be truly effective, safety culture and community learning structures must be built to facilitate the interaction of researchers, educators and students from multiple disciplines. This effort is aimed at integrating multiple interests into one community, a community of safety practice. In addition, educational programs must be recast to produce a new breed of researcher prepared and suited to working at the interface of multiple disciplines, thereby creating a second type of integration, a new learning community. However, several barriers must be overcome to achieve both forms of integration effectively. Progress has been made in developing international curriculum and building research communities at universities to approach problems in health and safety, systems biology, and frequently these communities are built around graduate students and their education. I this paper, we discuss challenges to and strategies for integrating students, staff and faculty from multiple disciplines to create new learning communities at the interface of biology, engineering and computer science.

2. A new approach to nanotechnology safety training

To be free of peril is a universal goal that has been common to all eras and all peoples. The desire to be safe and secure has always been an intimate part of human nature. Humanity becomes technical in the means to provide the objects and conditions necessary for sustenance and physical contentment.

Through the years, the content and method of "*safety training*" programs and organizational safety related problems have changed in two important ways. First, there is an increasing emphasis on total process safety as compared with the traditional focus on "*individual accidents.*" This is most obvious in the various aspects of organization liability and in areas relating to environmental impairment, and new technological risks. Second, there is an increasing need for formal cost-benefit justification for safety related activities, including training. In response to these needs, there is an increasing tendency of general management to think in terms of more formal safety related organizational training and global safety training programs to prepare personnel to deal with multidisciplinary nature of "*modern risk"* management. Unfortunately, existing safety training programs along with the safety professionals who conduct them, are often not prepared to deal with this global organization approach to safety. Systematic safety training reflects the major theme of this paper. Our desire is to maintain a position of organizational credibility and to implement safety training programs in the modern management environment. Therefore, in the proposed method, an implicit emphasis is placed on the need for formality and rigor in designing and conducting training and behavioral modification programs (i.e., safety culture) in today's modern legal and economic climate. More importantly, it is because the need for congruence between safety concerns (e.g., safety driven-design, new technology risks, etc…) and the demands of management is becoming increasingly evident.

Based on Bloom's taxonomy we understand that learning can start at any point, but inherent in that learning is going to be the prior elements and stages. In this sense, the use of systems concept for safety training provided new insights in the assessment of safety-critical systems. These new insights have led to systematic approaches to solving many safety problems and producing significant improvements. These improvements result from thinking about old safety problems (e.g., sloppy design, unreliable performance) in new ways: problem based learning framework, safety-driven design etc...).

In the past decade, Bloom's (1956, 1984), [2], taxonomy of educational objectives was developed as a tool for a variety of purposes. His taxonomy is organized from simple to complex, and concrete to abstract cognitive categories, representing a cumulative framework that has been widely applied in educational research, [7], [8]. More specifically, Bloom's categories reflect levels in knowledge construction. In this study, we have adopted Bloom's taxonomy as a "*style*" about learning goals to facilitate communication across persons, subject matter, and grade levels. Constructing knowledge implies movement from basic descriptive comments of opinion to using a variety of cognitive strategies, such as analysis, evaluation and creativity, [1]. However, there are conceptual and application limitations in using any taxonomy. For instance, Kunen et al. (1981) questioned whether evaluation should remain as the highest level of the original taxonomy. Former students of Bloom have revised the original taxonomy, [1]. Their changes especially affected the structure of the taxonomy. Instead of a unidimensional structure, they present a two-dimensional table. The knowledge dimension refers to the type of knowledge being learned (factual, conceptual, procedural, or meta-cognitive).

In the original concepts of Bloom's taxonomy, the cognitive process dimension refers to six levels in cognitive processing. These concepts are now reviewed and presented as active verbs, and two categories were changed as to their hierarchical position: evaluation and creating. In the context of the present study, we examine the latter possibility. Then, from systematic safety training aspects, and without lost of generality in safety engineering context where safety and reliability are the keys, we reformulated Bloom's cognitive process dimension as to be applicable to analyze system safety learning outcomes, safety culture, and the cognitive process used by students to design a system with lowest risks as low as reasonably practicable. Safety system training version of these concepts is illustrated in figure 1.

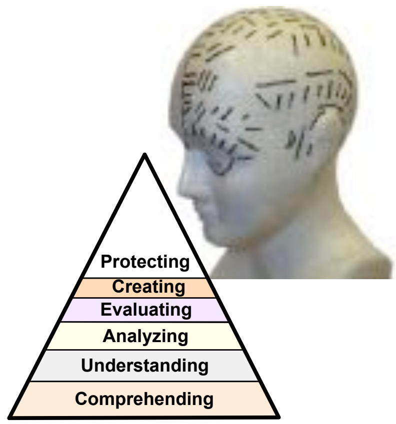

Fig.1 Modified Bloom's taxonomy for safety training objectives

Note that there isn't a magic bullet for engaging students. We developed this approach to assess the extent to which they engage in educational practices associated with high levels of learning and development of safety culture. We adopted Bloom's taxonomy to direct the analysis of international curriculum development contributions to system safety culture improvement. In the present study the taxonomy categories are not only adopted to analyze the cognitive processing level that this kind of development may provide. The present study also adopts the taxonomy as a scripting guide for the students. Students from diverse disciplines enrolled in environmental health and safety program were asked to add to each of their response to the survey questions a label that is based on one of the cognitive process categories in Bloom's taxonomy. Questions we asked were for example: what motivates and inspires the students who are attracted to the program, what types of careers do they plan to follow, and what specific issues are important to them?

This modified taxonomy attempts to account for the new behaviors and actions emerging as technology advances and becomes more ubiquitous. The design of this curriculum describes many classroom practices and learning objectives including the new processes and actions associated with communication technologies, the exponential growth in information, and increasing ubiquitous personal technologies or cloud computing.

3. The role of theory in nanotechnology safety training

Commercialization of nanotechnology will provide economic expansion and jobs but it also may have the potential to directly impact the workforce at large from two perspectives. First, to date a complete understanding of the health effects of workplace exposure to nanoparticles/nanomaterials is not available; consequently, safety and health engineering technologies and best practices are not currently in place to protect the workforce well-being along the lifecycle of nano-based products including workers in nanomanufacturing enterprises and the environment, and public health. Second, nanotechnology may potentially be used for the prevention, early detection, and treatment of occupational diseases (e.g., musculoskeletal disorders, pulmonary diseases), whose healthcare costs are burdening the US and global economies with billions of dollars.

Theory is needed to deepen the understanding of this new technology and the associated risks. The main purpose of the new curriculum is to present an education and research framework for the emerging interdisciplinary field of nanotechnology occupational and environmental health and safety to advance the field with respect to (1) the protection and promotion of worker safety and health in nanomanufacturing enterprises/environment and consumer public health, and (2) the prevention and treatment of occupational diseases through the use of nanotechnology.

Nanoparticles can have the same dimensions as some biological molecules and can interact with these. In humans and in other living organisms, they may move inside the body, reach the blood and organs such as the liver or the heart, and may also cross cell membranes. Without significant efforts to establish technologies and best practices in laboratories and work environments, the quality of life of the workforce may be affected because of potential adverse health effects of these new materials. Further, the dispersion of nanoparticles into the general environment and the impact of exposure to the general population need to be considered in a proactive manner.

The expected outcomes of the proposed education and research framework include, among others, (1) a roadmap and a guide for individual health and safety promotion and protection along the life cycle of nano-based products (i.e., nanomanufacturing enterprises, environment, product use, and disposal activities); (2) establishment of focus groups for advancement of integrated solutions and issues of immediate concern to individual health and safety in different nanomanufacturing sectors/environment/disposal activities, and health of public consumers of nano-based products.

Supplemental options that could be considered along with the proposed training program include guidance in how to establish the proper mix of slow and rapid change that includes strategic realignment with the past combined with an adaptive orientation towards the future. Of course opportunities to develop key competencies consistent with the challenges of advanced manufacturing, information technology, emerging materials, and other factors is necessary.

4. A framework for the education and research program

A variety of mechanisms at universities worldwide are addressing the dual challenges of conducting multidisciplinary, and often team-based, research projects in systems biology while also educating a new breed of researcher to assume leadership positions in this emerging field. Notably, California has the opportunity to create a 21st Century multi-ethnic workforce to meet the evolving and complex challenges of converging technologies—particularly nanotechnology, Micro-Electro-Mechanical Systems or “MEMS,” and advanced manufacturing technology—that will dramatically change the state’s manufacturing sector by 2015.

The proposed education and research program is centered on the impact of nanotechnology on occupational and environmental health and safety from two perspectives, (Figure 2). The life cycle of nano-based products envisioned is depicted in Figure 2. The education program will deal with integrated solutions and current issues of immediate concern to personnel who are currently or will be exposed to nanoparticles, nanomaterials, or nano-products and consumers of nano-based products. The research program will be centered on developing research agendas and dissemination of the latest research findings as outlined in Figure 2.

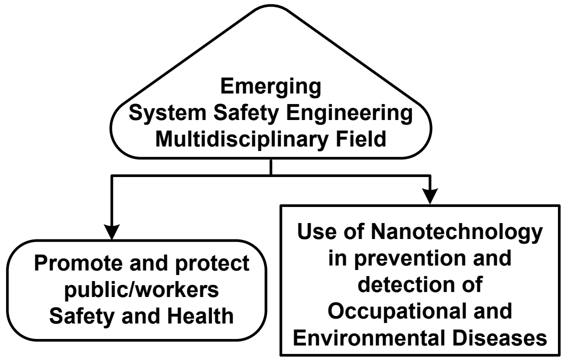

Fig.2 Broader objectives of nanotechnology occupational and environmental safety

At the University of Minnesota Duluth (UMD), we are finding that many students are well-suited to and interested in joint mentorship of their research by two faculty members with different backgrounds. By integrating fully into two research groups and learning how each one thinks and approaches problems, these students will be uniquely qualified to tackle non-traditional interdisciplinary research questions on their own. In addition, they will be well positioned to act as integrating agents in the community by serving as communications bridges or translators between two distinct research groups and approaches. Together, the emerging student profiles are beginning to define niches in the educational, cultural and research landscape of modern systems biology; the coming years will further refine the relationships among students, skills, classroom subjects and research areas that will further affect how learning communities in systems biology organize themselves.

The healthcare costs associated with occupational and environmental diseases are burdening the U.S. economy with billions of dollars. In fact, it is becoming a common practice for U.S. companies to send their manufacturing operations offshore largely due in part to the staggering health care costs in the United States. Nanotechnology may potentially be used for the prevention, early detection, and treatment of occupational diseases (e.g., musculoskeletal disorders, pulmonary and cardiovascular diseases). A major theme of the research program is to provide a platform to exchange ideas on nano-health technologies for the prevention and treatment of occupational and environmental diseases.

The main goals of the proposed research program will be accomplished through the following three aims:

- Provide a forum for the exchange of ideas and research agenda on nanotechnology impact on health and environment including (1) occupational health in nanomanufacturing enterprises, immediate surroundings, and disposal activities, and (2) consumer public health.
- Provide a forum for the exchange of ideas and research agenda on the use of nanotechnology in prevention, early detection, and treatment of specific occupational and environmental diseases.
- Disseminate the latest research findings on nanotechnology related to occupational, environmental, and public health and safety.

These goals are translated into specific research program advances by developing a national research agenda for the impact of nanotechnology on (a) occupational health along the life cycle of nano-based products. Moreover, they can deal with the dissemination of the latest research advances on nanotechnology occupational, environmental, and public health and safety. Topic examples include but are not limited to, exposure assessment and control, public health, and nano-health technologies for prevention, detection, and treatment.

Note that, balancing theoretical versus experimental science, it is not unusual to find that it takes much longer to obtain a degree in a highly experimental field than in a more theoretical field (computer science or mathematics). Moreover, in addition to academic excellence, system safety students need to be able to conduct complicated laboratory procedures and work alongside other researchers in large and relatively structured research laboratories. Students in more theoretical fields tend to have more freedom when choosing the place, time and type of their work, and there is little or no focus on manual techniques. These differences make collaborative research and educational efforts between engineers and biologists a challenging task for faculty, students and administrators. In addition to dealing with the academic demands, students interested in systems safety will need to be able to move smoothly between multiple worlds and cultures.

5. Conclusion

Academia and industry alike have started to respond to the challenges posed by nanotechnology. This perspective article has focused on the academic arena, where learning communities are forming to train a new breed of system safety researchers to work effectively on multidisciplinary teams at the interface of various disciplines (e.g., material science, biology, engineering and computer science). The characteristics of the emerging nanotechnology research communities might differ somewhat between academic and industrial settings, but we believe that the type of researcher who will succeed in an interdisciplinary environment and the mechanisms that hold these multidisciplinary communities together, on a fundamental level, will be alike. When educating future safety system engineers, the challenge goes far beyond introducing students to the foundations of and latest advances in each others' disciplines. The proposed program will have a broad impact on industry and the public. The integrated solutions for the protection and promotion of individual health and safety will touch upon the well-being of stakeholders exposed to nano-based products along its life cycle, that is, workers, public consumers, and military personnel.

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