Session 2625

**Safety, Health, and the Environment in the Engineering
Curricula: The Institute for Safety Through Design**

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There appears to be a need for the consideration of safety, health, and environmental issues in the design process. In response to this need, the National Safety Council Institute for Safety Through Design was established in 1995. The mission of this organization is to reduce the risk of injury, illness, death, and environmental damage by integrating decisions affecting safety, health, and the environment in all stages of the design process. One priority of this organization is the development of safety and health related material which can be integrated into the undergraduate engineering curriculum. A symposium was held in 1996 and another is planned for 1997 to bring together industry, government, and academic representatives to exchange information relating to safety, health, and environmental issues in the design process.

Section 1. Introduction/Background

In a presentation to the American Society of Safety Engineers Professional Development Conference in 1986, Alphonse Chapanis noted that, "To err is human, to forgive, design."¹ Chapanis' is suggesting that designers and/or design engineers have a responsibility to design systems not just to be safe, but to anticipate and "forgive" human error. He also suggests that, "The only true human errors are designer errors."¹ Chapanis' point is that system and equipment failures often attributed to user or operator error may, in fact, be more correctly attributed to designer error. In 1984, the National Institute for Occupational Safety and Health in the U.S. Department of Health and Human Services noted that, "Training is needed in Occupational Safety and Health for all engineering students and engineers so that they can deal with Occupational Safety and Health problems in their particular fields."² In 1985 the American Academy of Environmental Engineers (AAEE) proposed that, "Engineers, the individuals technically responsible for the design of industrial plants and processes, require health and safety awareness and related design skills if society is to prevent the existing major safety and health problems."³ More recently, in 1993, Kavianian, et al suggested that engineers must:

...develop a scientific approach to solving safety and environmental problems. This scientific approach must be incorporated into all aspects of engineering and management of hazardous technology. From conceptual design, feasibility studies, pilot plant operation, semi-works and commercial operation, to product shipment and waste disposal.⁴

They also noted that this can be accomplished only if engineers and managers, through proper training and education, are knowledgeable in a variety of safety and environmental health issues. Even more recently, in January 1996, in the Journal of Engineering Education it is noted that environmental health and safety issues must be placed at the "front end" of design. Doing this will require engineers whose intellectual skills and training extend beyond traditional "science focused" material, which has been the norm since the end of World War II.⁵

Section 2. Safety, Health, and the Environment: Engineers and Engineering Education

In 1992 Maine and Ward⁶ published the results of a survey intended to determine, "What do design engineers really know about safety?" Survey responses were received from 488 practicing engineers (311 members of ASME), 20 engineering faculty, and 52 engineering students. Engineers, faculty, and students all indicated that safety does contribute to product value. One disturbing note, however, is that students felt that safety contributed the most to product value, with faculty next, ASME members next, and non-ASME engineers least. Even though most engineers recognized that safety does contribute to product value, nearly 80% of the survey respondents had not taken a safety course in college and well over 60% of all respondents had not taken any safety short courses. Ninety percent of faculty had not taken a safety short course. Kavianian et al⁴ contended that while the public has placed considerable pressure on industry to advance technology, this social pressure has not manifested itself in increasing safety emphasis in the curriculum of engineering schools. The exposure of engineering students to hazard engineering and safety systems is minimal and most engineering schools have not included any general safety course requirement for an undergraduate degree in any engineering program. In response to this need, in the early 1980s the National Institute for Occupational Safety and

Health (NIOSH) initiated Project SHAPE (Safety and Health Awareness in Preventive Engineering) to enhance the safety awareness of safety engineering faculty and assist in the development of course materials for the integration of safety, health, and environmental concepts in the engineering curricula.

One significant problem is how to add additional safety and health related material to an already overcrowded engineering curriculum. In some situations, the University of Utah for example, the Board of Regents has established a maximum number of credits that can be required for a baccalaureate degree in any discipline. It has been proposed by Blosswick⁷ that there are two basic ways to include safety and health material in the engineering curriculum. One is by the development of elective and/or required undergraduate courses focusing on the engineering aspects of product, system, and occupational safety. The second is the development of course material which can be used by engineering faculty in "traditional" required undergraduate engineering classes. Rossignol and Hanes⁸ noted that the material to be integrated into existing classes can be in the form of lecture material, case studies, or laboratory materials. Dembe⁹ suggested that safety and health principles can be presented to undergraduate engineering students through the use of safety related examples to illustrate basic engineering concepts throughout various courses in the engineering curriculum. For example, problem sets, lecture materials, and projects may focus on course content and use analytical tools and methods taught in the course to deal with safety related issues. A sample of these is noted below.

Engineering Concepts	Safety and Health Examples
Statics and Dynamics	<ul style="list-style-type: none"> • Calculation of safety factors and performance limits • Rated capacities of hoists, cranes, scaffolding, storage racks, etc. • Floor loading
Mechanics and Kinetics	<ul style="list-style-type: none"> • Slip and fall protection • Properties of floor surfaces and optimal coefficients of friction • Biomechanical assessment of musculoskeletal system • Health hazards of segmental and whole-body vibration
Fluid and Gas Dynamics	<ul style="list-style-type: none"> • Ventilation of air contaminants • Design and hydrostatic testing of sprinkler systems • Safety properties of cryogenic fluids
Electrical Theory and Systems	<ul style="list-style-type: none"> • Protective and system grounding • Lockout/tagout-Zero energy state • Prevention of fires and electrical shock
Strength of Materials	<ul style="list-style-type: none"> • Fire safety in building design • Storage and transport of corrosive and reactive substances • Selection and testing of personal protective equipment (hard hats, safety shoes, etc.)
Product Design	<ul style="list-style-type: none"> • Product hazards assessment and control • Product life-cycle analysis (e.g., Installation, repair, maintenance, disposal) • Use of CPSC, ASTM and other safety-related standards

A basic format for the presentation of problem sets and case studies, based on work by the Center for Chemical Process Safety is shown below:¹⁰

Problem Sets

1. Engineering course or course type.
2. Safety and health concepts to be presented or included. An initial list of safety and health concepts is shown below.
3. Background. Briefly present the student with enough information on the safety and health concept or content so that they can apply it to the problem at hand. This need not be a great amount of detail but we can't just hit them cold with something that they haven't seen before.
4. Problem Statement. Present the problem in enough detail so that a student in the course, noted in item 1 with the safety and health content knowledge presented in item 2 above and discussed in item 3, can solve the safety and health related problem relating to the course.
5. Present hints, guidelines for solution. In the student version present some hints relating to problem solution. In the instructor's version present at least one problem solution, possibly overheads for problem discussion, references, and enough information so the instructor is able to discuss with the students the ramifications of different errors in the problem solution or the ramifications of different methods of problem solution.

Case Studies

1. Engineering course.
2. Safety and health concept.
3. Present the case and describe safety and health issues that actually were relevant in the "real world" situation.
4. Present the resolution or results of the case.
5. Discuss what might have happened had other approaches, other uses of safety and health information, other methods of attacking the problem, been used and discuss the results of these alternative methods of approaching the problem.

It is clear that, to be most effective, safety and health considerations must be included throughout the engineering curriculum. Courses related to engineering design, however, appear to be a most appropriate place to include this material. The American Academy of Environmental Engineers² notes that the incorporation of safety and health into undergraduate engineering education is particularly needed in courses on plant and process design. Valenti¹¹ notes that 40% of mechanical engineers with bachelors degrees considered design engineering to be their primary responsibility on their first job. He also notes that design for safety was noted by 80% of mid-level supervisors as being very important or somewhat important practices for new mechanical engineers. Incropera and Fox¹² note that "...design, interpreted broadly provided the best platform for launching appropriate curriculum changes." They also note that "Issues such as customer requirements, manufacturability, cost, safety/liability..."¹³ are to be included. One problem is the general lack of safety, health, and environmental material in design texts.

Maine and Ward⁶ note a lack of safety engineering methods and tools in "classic" design texts. They indicate that while there is some discussion as to why safety should be included in design

there is little, if any, as to how. In preparation for this publication, a review was performed on nine engineering design textbooks. These are noted in Appendix 1. Two of the reviewed texts, those by Middendorf and Ullman, both contain considerable material on the use of human factors engineering and the consideration of the human element in the design process. The text by Pahl and Beitz contained considerable information on safety principles and how to design for safety. The remaining texts, while perhaps excellent texts in classical design, contained relatively little (from a few paragraphs to a few pages) on safety and health issues. One text in this latter category is that used at the University of Utah in the senior level engineering capstone design course. At the University of Utah, safety and human factors material is included through a set of special lectures, handouts, and homework assignments. Students are required to perform a preliminary hazards analysis as part of a homework assignment during the middle of the term and their final project must include a more detailed failure modes and effects analysis. Students are also provided with information relating to ergonomics and are required to perform a review of potential ergonomic hazards during product assembly and product end use. It should also be noted that even the textbooks which include a considerable amount of general safety and/or human factors material do not provide a background on systems safety analytical techniques, which might be applied by engineering students to design processes in the future. For example, information or examples relating to preliminary hazards analysis, failure modes and effects analysis, and fault-tree analysis and were not included.

In conjunction with, and as a supplement to the earlier noted Project SHAPE, NIOSH has developed a set of instructional modules dealing with safety and health issues that can be used as course modules in existing engineering courses. These are listed below. NIOSH has also established a library of engineering cases relating to safety and health. These are also noted below.

NIOSH Instructional Modules

(NIOSH Publications 1-800-356-4674, 513-533-8573 fax)

- Bert, J.L. (1991, August). Occupational Diseases.
- Bethea, R.M. (1991, August). Incorporation of Occupational Safety and Health Into Unit Operations Laboratory Courses.
- Bloswick, D.S., Budnick, P.M. (1993, June). An Introduction to Electrical Safety for Engineers.
- Gute, D.M., Hanes, N.B. (1993, June). An Applied Approach to Epidemiology and Toxicology for Engineers.
- Kavarianian, H.R., Rao, J.K., Brown, G.V. (1992, March). Application of Hazard Evaluation Techniques to the Design of Potentially Hazardous Industrial Chemical Processes.
- Usmen, M.A. (1994, October). Construction Safety and Health for Civil Engineers.

NIOSH Engineering Case Library

(NIOSH Publications 1-800-356-4674, 513-533-8573 fax)

- Fothergille, J.W., Jr., Indoor Air Pollution Migration Transport Mechanisms in High-Rise Buildings.
- Gage, H., Human Factors in the Design of Machinery Controls.
- Heinsohn, R.J., Roaring Spring Foundry.

- North, D.L., Excessive Workplace Noise in the "Polymer" Department.
- Smith, C.O., My Aching Back.
- Taylor, R.K., Jur, T.A., How to Design, Manufacture and Install an Unsafe Blower System.
- Willis, T., Mechanical Power Press Safety Study.

Section 3. ABET and Safety Education (Accreditation Board for Engineering and Technology, 111 Market Place, Suite 1050, Baltimore, MD 21202, Tel 410-347-7700, Fax 410-625-2238, George D Peterson, Executive Director)

In it's 1985 annual report, The Accreditation Board for Engineering and Technology (ABET) indicated that "An urgent matter demanding attention by the Engineering Accreditation Commission (EAC) and the ABET Board of Directors is the need for significantly increased emphasis on safety and health, both occupational and public, in the education of engineering students."¹⁴ In it's current curricular objectives ABET indicates that, "Included are the development of...(4) an understanding of the engineers responsibility to protect both occupational and public health and safety."¹⁵ In it's current curricular content section ABET indicates that in engineering design, "...it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact."¹⁶ In the curricular content section it is also noted that, "An understanding of the ethical, social, economic, and safety considerations in engineering practice is essential for a successful engineering career."¹⁷ ABET has proposed Engineering Criteria 2000, to be published in 1998 for a three year phased implementation beginning in the 1998-99 accreditation cycle. In Criterion 4 (Professional Component) of this document ABET notes that:

The curriculum must prepare students for engineering practice culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, and social and political.¹⁸

The exact method by which ABET evaluators will determine the inclusion of "most of" the above noted considerations in the major design experience is as yet unclear. It does appear, however, that the senior level capstone design sequence will provide a ready made framework within which safety and health issues can be presented. At the University of Utah, for example, senior level mechanical engineering students are required to perform a preliminary hazards analysis on their design project early in the design process and a failure modes and effects analysis at an intermediate stage. In addition, they are provided with considerable information on ergonomics and design for assembly principles so that human factors issues relating to the proposed manufacturing process and end user can be included in the design process.

Section 4. National Safety Council Institute for Safety Through Design

In order to increase the safety knowledge of design engineers, The Institute for Safety Through Design (ISTD) was established in 1995 through the National Safety Council Foundation for Safety and Health. Initial funding of \$78,000 was provided by companies sharing the Institute's

vision that, "Safety, health, and environmental considerations are integrated into the design and development meant for human use." Based on this vision, The Institute has adopted a mission "to reduce the risk of injury, illness, death, and environmental damage by integrating decisions affecting safety, health, and the environment in all stages of the design process." The Institute is establishing liaisons with engineering schools, professional societies, industry, and labor organizations to increase the awareness of The Institute and its mission. It is proposed that the inclusion of safety, health, and environmental considerations in the design process will result in:

- significant reduction in injuries, illnesses, damage to the environment and resulting costs
- improvement in productivity
- decrease in operating costs
- avoidance of design shortcomings and expensive retrofitting

In September 1996 a symposium for engineering educators and industry managers held with the aim to identify the knowledge relating to safety, health, and the environment that an engineer (mechanical, civil, electrical, or other) should possess upon completion of a baccalaureate degree. The symposium was endorsed by the Department of Mechanical and Aerospace Engineering, Illinois Institute of Technology; Robert R. McCormick School of Engineering and Applied Science, Northwestern University; Department of Mechanical, Industrial and Nuclear Engineering, University of Cincinnati; and the Department of Mechanical Engineering, University of Utah. There were industry and labor representatives from Bayer, Boeing, GM, John-Deere, Rohm and Haas, Sara Lee, Communication Workers of America, consulting organizations, and others. Representatives of 14 educational institutions participated.

In the keynote presentation Jim Rucker, Executive Director of Industrial Engineering for GM, North American Operations noted that GM and other businesses cannot afford to retro-fit future engineers, and that while General Motors, as a pro-active action has established a design in safety office to address GM's need in general industry has no process or methodology to incorporate safety issues in the early stages of design. Joe Speilman, Vice-President and General Manager of the Metal Fab Division for General Motors Corporation noted that:

New engineers, entering our workforce, need to walk through the door with a basic knowledge of occupational health and safety already in hand. The National Safety Council's initiative to create a working Institute for Safety Through Design is absolutely critical to this nation's future.¹⁹

Brian Ahlschwede from John Deere's Product Engineering Center noted that safety activities must be moved as early as feasible in the product design cycle and that these process design cycles are getting shorter, from 5-7 years in the 1970's to approximately 2 years in the 1990's. He also noted that engineers must understand the basic elements of a safety program and how to effectively integrate them into the design process. Robert Bethea of Texas Tech University discussed the successful efforts at Texas Tech to integrate safety and health considerations into the undergraduate chemical engineering curriculum. Robert E. McClay, Jr. (Associate Professor, Safety Sciences Department, Indiana University of Pennsylvania, Indiana, PA 15705, (412) 357-3274, jjcb@grove.iup.edu) presented proposed safety and health learning objectives for undergraduate engineering programs in chemical, mechanical, civil, electrical, and industrial engineering programs developed by The Joint Council for the Safety, Health, and Environmental Education of Professionals (JCSHEEP).

Six roundtable sessions were spread over the 2 1/2 day meeting and focused on methodologies for incorporating safety, health, and environmental issues into the engineering curriculum and to identify the knowledge an engineer should have upon completion of a baccalaureate degree. Results are being formally summarized and will be published in a proceedings in the first quarter of 1997. The participants enthusiastically supported one conclusion: That knowledge must be presented to student engineers as an integral part of their curriculum. Participants noted that safety and health education should start during the freshman level introduction to engineering course(s), and continue throughout the curriculum and be an integral part of the senior level capstone design sequence. Participants also noted that safety and health principles can be included in required courses throughout the curriculum by the development of course modules, case studies, and safety and health problem sets which can be used in required courses of all engineering disciplines.

Several roadblocks to increasing the safety and health content of the engineering curriculum were also noted. These included the already overcrowded engineering curriculum and the struggles of engineering faculty to secure tenure. It was suggested that department heads and deans be encouraged to recognize and reward faculty when they are able to be creative and include safety and health principles in their courses. It was also noted that deans and department heads tend to respond to industry demand. Industry can have a positive affect on the inclusion of safety and health in the engineering curriculum by asking students during interviews what safety related courses or training they have had and by influencing engineering deans and department heads through the industrial advisory councils.

The 1997 Institute for Safety Through Design Symposium is scheduled for August 19 & 20 at the Indian Lakes Resort in Blommingdale, Illinois. The theme of the symposium is "World Class Safety Through Design Programs". The ISTD has invited papers which describe implemented safety through design programs, including benchmarks utilized in measuring safety through design programs, and information on methodologies for implementation of safety through design programs. The ultimate aim of The Institute and the symposium is to have safety, health, and environmental considerations embedded in curriculum materials, so graduate engineers utilize these concepts from day one of their professional careers.

In addition, the ISTD advisory committee identified the following priority efforts relating to inclusion of safety, health, and environmental materials in the undergraduate engineering curriculum:

- 1) Development of modular materials and case studies.
- 2) Development of material for senior level capstone design courses.
- 3) Development of course material for freshman/sophomore level courses.
- 4) Development of problem sets and other teaching toolbox material for required undergraduate engineering courses.

These efforts will help meet the immediate need for curricula materials and also provide information which can be used by authors of engineering design texts in the future. One means of evaluating the effects of these efforts will be to review ABET evaluations of engineering programs which use this material. It is hoped that more specific assessment methodologies can be developed.

In 1997 task groups will be formed to manage each of the above projects. Applications to participate on these task groups are welcomed. Please send a brief one-page resume and a description of past and current involvement in efforts related to safety through design to: Wayne Christensen, address noted below.

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The University of Utah and the ISTD are planning to submit a grant to the Centers for Disease Control to assist with a conference/workshop for engineering educators. The goal of this workshop will be to review and distribute available course materials and secure feedback from potential and present users of the material.

1. Chapanis, A. (1986). To Err is Human, to Forgive, Design. Paper presented at ASSE Professional Development Conference.
2. U.S. Department of Health and Human Services. (1984). Engineering Control of Occupational Safety and Health Hazards (DHHS Publication No. 84-102). Washington, DC: U.S. Government Printing Office.
3. American Academy of Environmental Engineers. (1985). The Need to Address Occupational Health and Safety in Engineering Education Programs. Annapolis, MD: Whitmore Printing.
4. Kavarianian, H.R., Meshkati, N., Wentz, C.A., and Rao, J.K. (1993, June). Should Engineering Schools Address Occupational and Environmental Safety and Health Issues?, Professional Safety, 48-49.
5. Ernst, E.W. (1996, January). The Editor's Page. Journal of Engineering Education, 1.
6. Maine, B.W. and Ward, A.C. (1992). What Do Design Engineers Really Know About Safety?, Mechanical Engineering, 44-51.
7. Boswick, D.S. (1990, April). Safety and Ergonomics in the Engineering Curricula: Non-Traditional Approaches, Proceedings of Workshop on Integration of Safety and Health into the Engineering Curricula.
8. Rossignol, A.M., and Hanes, N.B. (1990, April). Introducing Occupational Safety and Health Material Into Engineering Courses, Engineering Education, 419-432.
9. Dembe, A.E. (1996, April). The Future of Safety and Health in Engineering Education, Journal of Engineering Education, 163-167.
10. Center for Chemical Process Safety. (1990). Safety, Health, and Loss Prevention in Chemical Processes: Instructor's Manual. New York: American Institute of Chemical Engineers.
11. Valenti, M. (1996, July). Teaching Tomorrow's Engineers, Mechanical Engineering, 64-69.
12. Incropera, F.P., and Fox, R.W. (1996, July). Revising a Mechanical Engineering Curriculum: The Implementation Process (p. 233), Journal of Engineering Education, p. 233-238.
13. Incropera, F.P., and Fox, R.W. (1996, July). Revising a Mechanical Engineering Curriculum: The Implementation Process (p. 234), Journal of Engineering Education, p. 233-238.
14. Talty, J.T. (1986). Methods of Integrating Health and Safety Into Engineering Curricula, ASCE Annual Conference Proceedings.
15. Accreditation Board for Engineering and Technology. (1995-96). Criteria for Accrediting Programs in Engineering in the United States, (Section IV.c.2). Baltimore, MD: Author.
16. Accreditation Board for Engineering and Technology. (1995-96). Criteria for Accrediting Programs in Engineering in the United States, (Section IV.c.3.d(3)(d)). Baltimore, MD: Author.
17. Accreditation Board for Engineering and Technology. (1995-96). Criteria for Accrediting Programs in Engineering in the United States, (Section IV.c.3). Baltimore, MD: Author.
18. Accreditation Board for Engineering and Technology Board. (to be published 1998). ABET Engineering Criteria 2000.
19. National Safety Council. (1996, October 7). National Safety Council News, p. 2.

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Wayne C. Christensen, CSP. Wayne is the Program Director of the National Safety Council Institute for Safety Through Design. He has over 30 years of experience in the safety field and has held national managerial positions in ASSE.

Robert B. Roemer, Ph.D. Bob is Professor and Chair of the Department of Mechanical Engineering at the University of Utah. He has particular interests in the development of the senior level capstone design course and the integration of safety, health, and environmental issues into the engineering design curriculum.

APPENDIX 1

Reviewed Engineering Design Texts

Dieter, G.E. (1991). Engineering Design: A Materials and Processing Approach. New York: McGraw-Hill.

Dixon, J.R., and Poli, C. (1995). Engineering Design and Design For Manufacturing: A Structured Approach. Conway, MA: Field Stone.

Ertas, A., Jones, J.C. (1993). The Engineering Design Process. New York: John Wiley & Sons.

Middendorf, W.H. (1986). Design of Devices and Systems. New York: Marcel Dekker.

National Research Council. (1991). Improving Engineering Design. Washington, DC: National Academy Press.

Pahl, G., Beitz, W. (1988). Engineering Design: A Systematic Approach. United Kingdom: Design Council London.

Pugh, S. (1991). Total Design: Integrated Methods for Successful Product Engineering. Wokingham, England: Addison-Wesley.

Ullman, D.G. (1992). The Mechanical Design Process. New York: McGraw-Hill.

Ulrich, K.T., and Eppinger. (1995). Product Design and Development. New York: McGraw-Hill.