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Bringing Human Factors into Engineering Education Realm - A Case Study: Teaching Human Factors in Fire Protection Engineering

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Human-factors engineering has long been considered an integral part of engineering. It focuses on the application of human physical and psychological characteristics to the design of engineering devices/systems so that the products and solutions can better serve human needs. There has been a long history of efforts[1,2] in incorporating human factors in engineering education, such as teaching ergonomics in product and space design. However, this idea and practice has not been widely implemented in the area of fire science and engineering education: little or limited emphasis of human factors is included in current curriculum. In fact, human behavior in fire is *at the core of* all fire safety regulations, projects and service actions. It is the basis of various engineering solutions for fire safety. Therefore, it is of imperative necessity to teach students to look at fire protection from human perspective, and understand the human factors that have shaped a variety of problem-solving in the field of fire protection engineering.

1. Transform the idea—course design

To transform the idea into teaching practice, a new course, *Human Behavior & Fire Protection*, was designed and attempted in the fall semester of 2016, 2017 and 2018. This course is offered to undergraduate Engineering Technology students in the Fire Science program (B.S.) in College of Engineering. This course introduces various human behaviors during fire emergency with a focus on interactions among fire, building, and occupants. It examines human decision-making process in a fire emergency, i.e. how people become aware of the fire and make decisions for evacuation or protection. It examines various behaviors during evacuation, including panic behavior, re-entry behavior, delayed evacuation, crowd behavior, exit pattern, etc. Furthermore, the course discusses how these behaviors may affect the engineers to design safe egress path and effective protection systems such as fire detection, suppression and smoke control system, and how these behaviors may affect fire service/first response team to perform life-saving tasks. Another key issue examined in this course is the responses and behaviors of disabled/impaired/aging population under fire situation. Engineering and management solutions to accommodate their special needs during fire emergency are studied in detail, correspondingly.

1.1. Plan for specific learning outcomes

At the early stage of course planning and designing, the following questions were asked:

- What should be the teaching goals and learning outcomes of this course?
- What are the components that should be included/covered in the curriculum to achieve these goals/outcomes?
- What are the best teaching approaches to achieve these goals/outcomes?

The exploration started with the first question. Since the new course is planned to help students develop a practical and technical understanding of concepts related to human factors in fire protection, in course planning stage, an official document from SFPE (Society of Fire Protection Engineer), "Draft of the SFPE Guide to Human Behavior in Fire, 2nd edition"[3], was adopted as guideline and framework to establish teaching goals/learning outcomes for this course. Based on the information collected from the document, after taking this course, students should be able to establish an overall picture of the role of human factors in fire protection engineering. To be more specific, the course will help students achieve this goal through offering lessons in the following *six categories*:

- **Emergency decision-making:** understand human decision-making process in a fire emergency
- **Human behaviors in fire:** learn about various human behaviors in fire.
- **Evacuation in fire:** learn about stages and strategies of evacuation in fire.
- **Building egress system design**: understand how building egress system design is affected by various human responses and behaviors in fire.
- **People with disabilities:** learn about the special needs of certain population in fire emergency, including aging population and disabled/impaired population.
- **Current research methods and engineering tools:** learn about scientific methods and tools used in the field to study human factors in fire.

1.2. Design the curriculum to achieve the learning outcomes

Moving to the 2nd question, to achieve the learning outcomes indicated above, it was determined that this course discusses the specific topics in the following *six areas*, correspondingly:

1) Decision-making in a fire

This section discusses how people become aware of a fire emergency via a variety of visual, auditory and cognitive cues, such as smoke, light, noise, movement, fire alarm, peer action, etc. Particularly, the function and mechanism of fire alarms, a key component in fire protection engineering system, are examined. Students learn about the type and working mechanism of fire alarm system, effectiveness and failure of fire alarm under various conditions, as well as how fire alarm is related to other components of fire protection system, such as fire suppression system and smoke control system.

Further, this section introduces theories of decision-making models in a fire emergency. After studying the decision-making process, students are guided to think about why people respond differently, i.e. make different decisions, to the same threat cues. For example, students consider the differences in decision-making by a building occupant, a visitor, and a fire service officer.

2) Various human behaviors in a fire

This section discusses theories of human fire behaviors and identifies a variety of behaviors in a fire, including disaster shock, panic behavior, re-entry behavior, fire-fighting behavior, protecting behavior, group behavior, etc. It goes deep into these behaviors, examining when and why they occur in a fire event and how they may impact the evacuation and fire rescue.

3) Evacuation in a fire

This section discusses evacuation concepts, strategies and methods, including occupants characteristics in the context of fire evacuation, components/phases of evacuation, flow rates during evacuation (such as flow rates down stairs in high-rise building and flow rates on horizontal passageway), egress flow and capacity calculation; a variety of evacuation strategies and methods, such as the role of directed evacuation, crowd control and management, etc.

4) Building egress system design

This section examines the core components of a building egress system, such as fire rated door, panic hardware, stairwell, elevator, escalator, emergency lighting, exit passageway, refuge area, and so on. Criteria for egress paths/exits design are examined in detail. In addition, the engineering measures such as fire barrier and smoke control that protect the egress system safe from fire damage are introduced. For instance, how a fire-resistance-rated structural frame and a fire-rated exit enclosure in the building are capable of withstanding stresses imposed by fire are discussed.

5) Disabled or impaired occupants in a fire

This section discusses the various challenges that people with disabilities might have during evacuation. Particularly, the evacuation in a health-care facility is used as an example to examine these challenges. In addition, current approaches, from strategies to technologies, for evacuation of people with disabilities are discussed.

6) Design & Research methods

This section discusses the major research methods for involving human factors in fire protection engineering design, including using engineering tools to model human behaviors in fire. For example, PATHFINDER[4], a computer-based evacuation modeling tool is introduced.

2. Think out of the box—connecting textbook with the real world

Next, what would be the best teaching approach to achieve the teaching goals and learning outcomes? According to educational research, project-based learning (PBL) has become a favored pedagogical model for teaching engineering knowledge and skills in addition to chalk-and-talk teaching. Through engaging students in the investigation of authentic problems, PBL can enhance student participation in active and self-learning and promote critical and proactive thinking[5,6,7]. Therefore, during course design, it was determined that it would be insufficient to limit the learning of human factors in fire science and engineering on paper. Projects that require the application of knowledge leaned from lectures to real-world cases/projects are planned in the curriculum.

For example,

- after learning about function and mechanism of fire alarm system, students work on an assignment to further research effectiveness of fire alarms in various situations, including effective alarm system for people with disability. In this project, students are encouraged to propose innovative solutions to alert all kinds of occupants in a fire emergency. Some ideas include adopting built-in shaking alarms in a wheel-chair or bed, placing pre-recorded parents' alerting voices as alarm in young children's bedroom, etc.

- after learning about using public announcement tool as fire alarm, in an assignment students are asked to write a draft of an alarm message to be announced when there is a fire in a cinema, considering the features and key components that a successful warning message should contain.

- after learning about emergency decision-making models, in an assignment students are asked to research and compare the different occupants' responses during evacuation on Sep. 11, 2001, in the two World Trade Center towers, WTC 1 and WTC 2, and find out what caused the different decisions and behaviors.

- after learning about the egress system design, students are asked to investigate the engineering building in which they have lectures. They lay out the egress paths/exits and study how they are protected from a fire via various methods/elements, such as fire barrier, smoke exhaust fan, staircase pressurization, etc.

- After learning about various evacuation paths in a building, students are asked to investigate skybridge as an option for evacuation in highrise buildings. They read about relevant literatures and find out the feasibility of adopting skybridge as a means of evacuation during a fire emergency. Some students proposed the question: if there were a skybridge between the two towers of World Trade Center, we might have a different story about evacuation on Sep. 11, 2001.

In addition, two course projects are planned with a purpose of knowledge application and generalization. Students are asked to examine building fire safety features and fire protection engineering solutions in a real building, and find out the human factors that impacted/shaped these features/solutions. Furthermore, they are encouraged and challenged to propose better design solutions based on the understanding of human behaviors in a fire.

The first course project requires an in-depth research and investigation of evacuation in a high-rise building. Through this project, students investigate a specific high-rise building and find out the answer to the questions including the typical fire hazards/threat in a high-rise building, the differences between high-rise evacuation and low-rise evacuation, typical fire protection strategies and solutions in a high-rise building evacuation, means of egress system design, crowd control and management in high-rise building evacuation, fire-fighting strategies for high-rise building fires, etc. Particularly, they are challenged to examine the traditional approach and seek alternative solutions. For instance, students answer the question, "why are occupants traditionally prohibited to use elevator as a means of egress?" "Can elevator be adopted as an effective and efficient evacuation tool in high-rise building? If yes, what kind of fire protection measures for the elevator need to be implemented?" They are encouraged to think out of the box and research on possibility of using elevators as a means of egress for high-rise building during a fire.

The second course project requires students to perform research on issues associated with evacuation of people with disability. Students investigate different types of disability, including mobility impaired, sensory impaired (blind/deaf/hearing loss), intellectually impaired, multiple disabilities (e.g. senior citizen), and find out the specific challenges faced by each group. They investigate or propose customized solutions to facilitate the evacuation of each group.

Through these teaching efforts, students are first guided, then challenged to build connections between textbook and real world cases/projects, with a focus on examining human factors behind current fire protection measures and engineering approaches, as well as on seeking solutions for better future systems.

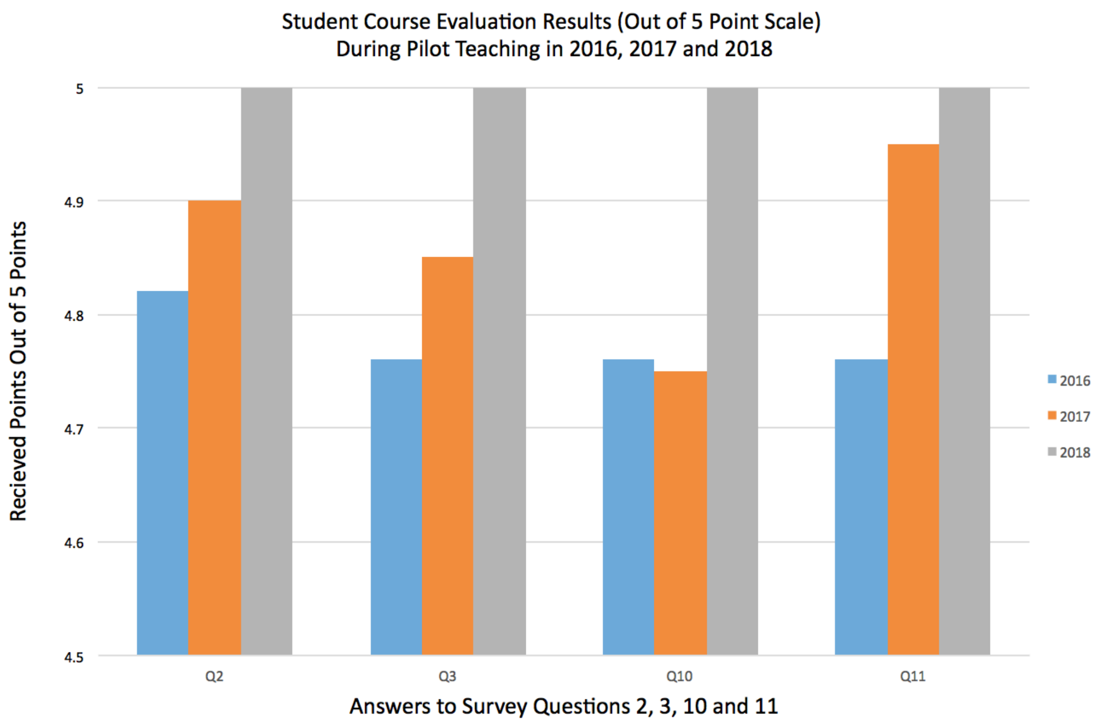
3. Learning outcomes achieved, lessons learned, and future work

Through pilot teaching in the first three years, the ideas and methods of incorporating human factors in fire science/engineering curriculum are explored and tested. Compared with traditional technical courses that teach engineering systems with a focus on "what it is" and "how it works", this course discusses "why it may work or may not work" with an emphasis on human factors that *shaped* current approaches and solutions. Further, this course challenges and encourages students to explore "how it may work better" through examining these human factors. Students' learning outcomes are evaluated through weekly assignments and quizzes, final exam and course projects.

So far the feedback from students are very positive and encouraging. Data collected from post-teaching survey in 2016, 2017 and 2018 show that this course has received high students evaluation. Overall this course received an average of 4.75 in fall 2016, 4.82 in fall 2017, and 4.95 in fall 2018 (based on a 5 point scale). Among all the eleven survey questions, the four questions closely related to course design and learning outcomes all received very high scores. Please see the notes and graphs below.

Survey questions related to course design and learning outcome:

Q2. The readings and assignments contributed to my understanding of the subject.
Q3. Exams, projects, papers, etc were good measures of the course material.
Q10. The course contributed to my intellectual growth and/or helped me develop useful skills.
Q11. Overall the instructor was an effective teacher.



During the course surveys in 2016, 2017 and 2018, the participation rates were high (more than 80% of the students each year provided feedback). Therefore, to a relatively accurate degree the data represented how students thought about this course. As seen from the graph, all scores were above 4.75 out of 5.0. Each year after teaching I refined the teaching plan and updated course materials according to students' comments and most recent fire incidents as well as industry trends. Each year more real-world related problem-solving were included into assignments. According to the course survey comments, students liked the new perspectives of examining fire incidents/technology from human factor point of view, which opened a whole new field for them. They also liked the PBL-based learning style. Therefore, as shown on the graph, the evaluation scores were increasing year by year.

To summarize, through taking this course, as it was purposed, students have learned to link human factors with the fire protection systems/approaches. It is expected that the positive impact may expand to students' learning experiences with other courses in the fire science program. For example, with the perspectives and techniques learnt from this course, students should be able to apply the gained analytical skill to recognize the impact of human factors on building/fire codes, standards and laws, on fire protection problem-solving in building design and construction, on management of hazardous/flammable material and fire-safe community planning, etc.

One of the major lessons learned from pilot teaching is, *case study*, as an effective tool, plays a key role in helping students establish the connection between phenomena, and it can be used in different learning context. For instance, it is found that one of the most effective teaching approaches in this course is to use a case study in the lecture to elucidate the theme, then ask students to further explore the theme via another case study in the assignment.

Based on the pilot teaching practice, collected feedbacks and reflections, the future work planned include:

1) Current curriculum only discusses the impact of human factors on fire protection in a general context. It is planned in the future to include case studies to examine the human behavior issues in a variety of building occupancies, such as shopping center, transition center, office, theatre, night club, healthcare facility, residential building, industrial building, etc. Discussions will be more specific since they target specific type of building occupancy.

2) Currently the discussion of human factors in this course emphasizes the link between occupant evacuation and building egress system. It is expected that in the future teaching practice more "links" could be explored, such as human factor and special hazardous material/system, human factor, fire dynamic and fire suppression, etc.

It is anticipated that this teaching practice will help push forward the effort of involving human factors in fire science/engineering education and help students achieve a better learning outcome toward creating "humane" fire engineering solutions for buildings.

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