2016

A Teaching Module for Engineers on Robotic Safety: Approaches and Effectiveness

Mark A. Rosen
University of Ontario Institute of Technology, marc.rosen@uoit.ca

Dan Zhang
York University, dzhang99@yorku.ca

A Teaching Module for Engineers on Robotic Safety: Approaches and Effectiveness

Marc A. Rosen

Faculty of Engineering and Applied Science

University of Ontario Institute of Technology, Oshawa, Ontario, Canada

Dan Zhang

Lassonde School of Engineering

York University, Toronto, Ontario, Canada

Presented at the Higher Education in Transformation Symposium

November 2 - 4, 2016 in Oshawa, Ontario, Canada

Author Note

The authors acknowledge the efforts of Bin Wei and Guohua Cui, University of Ontario Institute of Technology, in helping to draft the teaching module on which this article is based, and Zhen Gao, University of Ontario Institute of Technology, for using the teaching module in a course and delivering the survey that is reported on in this paper. The authors are also grateful to Minerva Canada and Mitacs for supporting the development of the teaching module on which this article is based.

Abstract

A teaching module recently developed by the authors for engineers on robotic safety using various approaches (Powerpoint presentation and written document) is described and an assessment of the effectiveness of using the module is presented. The effectiveness of the teaching module and its different approaches is assessed by using it in a class setting, and surveying the opinions of the students. The content delivery approaches and learning approaches are also assessed, based on student opinions. The teaching module is determined to be effective at promoting student learning on robotics safety, and to offer multiple useful delivery modes. The teaching module thus allows students with different learning preferences to exploit the delivery mode the find most suitable.

Keywords: teaching module, teaching effectiveness, robotics, safety

Introduction

Health and safety are important considerations in many fields. Health and safety are especially critical considerations in engineering, in terms of both the health and safety of the public as well as occupational workers. This is continually confirmed by professional engineering associations, which usually state that health and safety are of utmost importance in engineering practice. For example, Professional Engineers Ontario (http://www.peo.on.ca) states in its Code of Ethics, “A practitioner shall … regard the practitioner's duty to public welfare as paramount.”

As a consequence, sound and meaningful education and training in engineering health and safety is recognized as important and necessary. Engineering programs almost always must appropriately address health and safety to maintain accreditation. For instance, the Canadian Engineering Accreditation Board (http://www.ccpe.ca) includes in its curriculum-content criteria, “Appropriate exposure to … public and worker safety and health considerations … must be an integral component of the engineering curriculum.”

A wide array and type of educational resources on health and safety exist in areas such as engineering, health, management. These include methods for assessing and mitigating of hazard risks and consequences. The resources available include general books and related resources (Bahr, 1997; Christensen & Manuele, 1999; Covello & Merkhofer, 1993; Fullwood & Hall, 1988; Goetsch, 2001; Hammer & Price, 2000; Henley & Kumamoto, 1981; Kumamoto & Henley, 1996; Lawson, 1992; Minerva Canada, 1998; Modarres, 1993; Montgomery & Kelloway, 2002; Roughton & Mercurio, 2002; Scherkenbach, 1991; Taylor, 1994; Woodside & Kocurek, 1997), specialized materials produced by safety or safety-related agencies (CCOHS, 2016; CSSE, 2016; Health Canada, 2016; IAPA, 2016; International Labour Organization, 2016;

Minerva Canada, 2016; NIOSH, 2016; OSHA, 2016; Ontario Ministry of Labour, Health and Safety, 2016; Professional Engineers Ontario, 2016; WSIB, 2016), company-based health and safety materials posted on company web sites (DuPont Canada, 2016; Ontario Power Generation, 2016; Imperial Oil, 2016), and specialized resources located throughout company and agency web sites (NIOSH, 2016; Ontario Ministry of Labour, 2016; Ontario Ministry of Labour, 2016; OSH for Everyone, 2016; Workplace Safety and Insurance Board, 2002). Minerva Canada, for instance, has developed and made freely available many educational case studies on health and safety, including one entitled "Engineering Health and Safety Module and Case Studies", developed by one of the authors (Rosen, 2004).

Teaching modules on health and safety are viewed by many as effective and useful tools for educating about health and safety. Minerva Canada has recently developed a suite of teaching modules on health and safety and posted them on its web site (Minerva Canada, 2016). The teaching modules cover such topics as safety in transportation of dangerous goods, reactive chemical hazards, nano safety, risk management, hazard and risk identification, process safety management, electrical safety, radiation safety, robotics safety, public safety, codes and regulation, quantitative risk assessment, emergency preparedness and crisis management, and laboratory safety management. Also, the National Institute for Occupational Safety and Health (NIOSH) posts several safety and health awareness for preventive engineering modules: agricultural safety and health for engineers, an applied approach to epidemiology and toxicology for engineers, an introduction to electrical safety for engineers, application of hazard evaluation techniques to the design of potentially hazardous industrial chemical processes, construction safety and health for civil engineers, fire protection, incorporation of occupational safety and

health into unit operations laboratory courses, occupational diseases, system safety and risk management (NIOSH, 2016).

This article focuses on a teaching module on robotics safety, which was developed by the present authors recently for Minerva Canada. Robotics is an advanced course, usually included in such programs as Mechanical Engineering and Electrical Engineering, as well as in less common programs like Mechatronics Engineering and Manufacturing Engineering. The teaching module consists of three parts:

- a detailed and extensive written document on robotics health and safety,
- a related Powerpoint presentation, and
- multiple choice questions on robotics safety.

The module is available online at the Minerva Canada web site (http://safetymanagementeducation.com), and is described elsewhere (Zhang, Wei & Rosen, 2016).

To test the usefulness and effectiveness of the teaching module on robotics safety, it was implemented in a relevant course and the students were surveyed. This paper focuses on the results of that application of the teaching module. The objectives of this paper are twofold. First, we seek to assess the usefulness and effectiveness of a teaching modules on robotics safety in helping students learn. Second, we evaluate the effectiveness of the different approaches to teaching robotics safety embodied in the teaching module, where the approaches include self-learning and in-class instruction as well as a detailed written document and Powerpoint presentations.

Brief Description of Teaching Module on Robotics Safety

An overview of the teaching module on robotic safety developed by the authors for engineering students is described in this section. It covers different types of robots, types and

sources of robotics hazards, robot safety requirements, robot safeguards and robot safety standards. The importance of safety is highlighted throughout, especially for practical industrial applications. Some new emerging engineering safety trends and features related to robotics are also discussed.

Part I of the teaching module provides an introduction to robotics safety. It points out that around 12-17% of accidents in industries using advanced manufacturing technologies have been reported to be related to automated production equipment, including robots, and that tasks often involve human interaction, necessitating proper safety training for employees and the proper use of appropriate safeguards. Robotics safety operates under a set of principles, primarily related to how to protect humans from robot motions. It is stressed in this part that the principles of robotics safety and the systems to be used when working with robotics are the essence of the teaching module.

Part II describes types of robots and industrial robots. A robot is a mechanical or virtual intelligent agent that can perform tasks automatically or with guidance by remote control. It typically has the capacity for sensory input (vision, touch, etc.), recognition and movement. The main types of robots today include industrial robots, military robots, medical robots (Fullwood & Hall, 1988), mobile robots, service robots, and micro and nano robots. It is explained how robots can be classified according to various aspects, such as design configuration, control system, path generation, and others. Industrial robots have four major components: mechanical unit, power source, control system and tooling, and these are described.

Part III describes types and sources of robotics hazards. The main types of robot accidents are discussed. Robotic incidents can be grouped into four categories: impact or collision accidents, crushing and trapping accidents, mechanical part accidents, and other

accidents. It is also explained how the potential hazards posed by machines to humans can be assessed and broken down by source/cause, as follows: human interaction, control error, unauthorized access, mechanical failure, and environmental source.

Part IV of the teaching module covers robot safety requirements. It is explained that the majority of industrial robot incidents and accidents do not take place during normal operation. When working with industrial robots and installations, there is an emphasis on special operation modes, such as commissioning, setting up, programming, testing, checking, troubleshooting and maintenance. In these operating modes, personnel are usually in a danger zone, so safety measures are required to protect them from hazardous events. Hence the module describes both the requirements and safety measures in normal operation, where the use of robot technology necessitates hazard analysis, risk assessment and safety measures, as well as the demands and safety measures for special operation modes (e.g., setting up, programming). The module then describes measures to provide reliable safety control systems: redundant and diverse layouts of electromechanical control systems, redundant and diverse set-ups of microprocessor control systems developed by different teams, safety barriers, and redundant control systems that take in account failures.

Part V identifies robot safeguards, starting from design and following through to operation. The need for risk assessment in designing a safe robot system is explained, as is the need for considering health and safety throughout the design. For the planning stage, installation and subsequent operation of a robot or robot system, it is demonstrated that the following need to be considered: safeguarding devices, awareness devices, perimeter fencing, presence sensing devices, and manipulator position indication and limiting. Instruction to improve robot safety is also covered.

Part VI identifies and discusses robot safety standards, explaining that these are critical to ensure safety in the workplace through codifying the safety requirements for humans working around industrial robots.

Approach and Data

A survey was developed to assess the effectiveness of the teaching module and the way it is utilized. The survey is shown in the Appendix.

The teaching module was utilized by a course instructor, Dr. Zhen Gao, on March 21, 2014 in the following class in the Department of Automotive, Mechanical and Manufacturing Engineering within the Faculty of Engineering and Applied Science at University of Ontario Institute of Technology: MECE3390U – Mechatronics. The course is taken by 119 engineering students, mostly in the third year of a four-year program in Mechanical Engineering.

In using the teaching module materials, the instructor spent around 1 hour delivering the teaching the module in class by using the Powerpoint presentation on robotic safety. Additionally, the instructor assigned as independent reading the accompanying written document on robotic safety. The instructor used questions provided with the teaching module to interact with the students and to help them better understand the information which was delivered in the lecture.

After the module was used, the survey was delivered to the students who attended the lecture. The students were given around 10 minutes to complete the survey. There were 32 respondents.

Results and Discussion

To assess the Teaching Module on robotics safety and its use, comments were provided to the students and they were asked to indicate if they agree and how strongly. Specifically, a five-point scale was provided: agree strongly (5), agree somewhat (4), neither agree nor disagree, i.e., neutral (3), disagree somewhat (2), and disagree strongly (1).

In the following subsections the comments that were provided to the students are listed, and the survey results and their interpretation are then provided.

Overall Effectiveness of Teaching Module

To assess the overall effectiveness of the teaching module on robotics safety, three comments were provided to the students and their feedback was sought. The comments are listed below, along with the results from the survey and their interpretation.

1. Overall, the module (including the Powerpoint presentation and the supplementary document) helped me understand why engineers should care about health and safety.

None of the respondents disagreed with this, and over 91% agreed somewhat or strongly. This suggests the module overall was very effective at helping engineering students understand why engineers should care about health and safety. This suggests that the teaching module helped instill in students the value of health and safety.

2. Overall, the module (including the Powerpoint presentation and the supplementary document) broadened my own understanding of health and safety in engineering.

None of the respondents disagreed with this, and almost 80% agreed somewhat or strongly. This suggests the module was very effective overall at broadening the understanding that engineering students have of health and safety in engineering. In particular, it is presumed that a large part of this was broadening the students' understanding of health and safety in engineering to the specialized area of robotics.

3. I was able to understand the contents of the module.

None of the respondents disagreed with this, and almost 90% agreed somewhat or strongly. This suggests the module was quite understandable engineering students, and thus communicates well its content on health and safety in robotics engineering.

Effectiveness of Module Components

In this section, we assess the effectiveness of the components (detailed and extensive written document on robotics health and safety, related Powerpoint presentation, multiple choice questions on robotics safety) of the teaching module on robotics safety. Four comments were provided to the students and their feedback was sought. The comments are listed below, along with the results from the survey and their interpretation.

1. The *Powerpoint presentation* portion of the module helped improve my understanding of robotics safety.

About 94% of the respondents agreed with this, and almost 70% agreed somewhat or strongly. This suggests the Powerpoint presentation module, typically used as part of a lecture, was quite effective as a tool for teaching engineering students about health and safety in engineering, and thereby facilitating their learning on this important subject.

2. The *supplementary document* portion of the module helped improve my understanding of robotics safety.

About 94% of the respondents agreed with this, and 72% agreed somewhat or strongly. This suggests the supplementary written document, typically used as a supplement to a lecture or as an independent reading exercise, was an effective as a tool for teaching engineering students about health and safety in engineering, and thereby facilitating their learning on this important subject.

3. The most effective way of utilizing the module would be to use only the *Powerpoint presentation*.

About 41% of the respondents agreed with this and 56% disagreed. This suggests the some users consider the Powerpoint presentation module adequate on its own as a tool for teaching engineering students about health and safety in engineering and thereby facilitating their learning on this important subject. But this result also suggests that another group of about the same size feels that the supplementary written document is also needed as a complement for effectively teaching engineering students about health and safety in engineering and thereby facilitating their learning on this important subject. In other words, the Powerpoint alone may not be adequately informative. This result may be attributable, at least in part, to the highly technical and complex nature of the subject of robotics engineering. It is often difficult with only Powerpoint to convey highly technical subjects adequately, especially when they have a high degree of complexity.

4. The most effective way of utilizing the module would be to use the entire module (i.e., both the Powerpoint presentation and the supplementary document).

None of the respondents disagreed with this, and about 64% agreed somewhat or strongly. This suggests a strong majority consider both the Powerpoint presentation module and the supplementary written document together to be an effective package for teaching engineering students about health and safety in engineering and thereby facilitating their learning on this important subject. But about one third feel, either tool may be adequate on its own. This probably reflects the redundancy which has intentionally been incorporated into the two tools, in case only one is used by an instructor.

Comparison of Independent Studies and Conventional Modes of Teaching

In this section, we compare learning through independent studies with conventional modes of teaching, from the perspective of the teaching module on robotics safety. Only one comment was provided to the students given the focused nature of the query. Again, student feedback to the comment was sought. The comments are listed below, along with the results and interpretation.

1. Compared to utilizing the module via the conventional lecture mode of teaching, utilizing the module by students in an *independent studies* manner would be more effective at facilitating learning about robotics safety.

About 62% of the respondents agreed with this, but only 6% disagreed. This suggests the material contained in the teaching module (Powerpoint presentation and/or supplementary written document) is adequately understandable and self-contained to be used as an independent studies tool for teaching engineering students about health and safety in engineering and thereby facilitating their learning on this important and technically complex subject. This may partly be a function of the students of today and how they learn, reflecting a preference for self-study rather than conventional lecture approaches.

Effectiveness of Evaluation

In this section, we assess the effectiveness of student evaluation methods used to determine the level of student learning on robotics safety, through use of the teaching module. Only one comment was provided to the students given the focused nature of the query. Once more, student feedback to the comment was sought. The comment are listed below, along with the results and interpretation.

1. The quiz questions were a meaningful and useful way of assessing how well I learned about robotics safety through the module.

About 72% of the respondents agreed with this, but only 3% disagreed. This suggests the quiz questions reinforce learning of the material and/or foster thinking about the content covered, and thus increased the effectiveness of the teaching module as a tool for teaching engineering students about health and safety in engineering and thereby facilitating their learning on this important subject. This may partly be a function of the interactivity and involvement it permits students as they learn. Additionally, the quiz questions appear to be especially useful for reinforcing student learning about robotics safety provided through the Powerpoint presentation and related written document.

Other Comments

The students were given the opportunity to provide written feedback through written comments at the end of the survey. This was intended to allow students to raise points not covered or captured through the survey questions, and also to amplify on their responses to the survey question.

Some comments were very positive, suggesting that the teaching module provides an excellent introduction to the topic of robotics safety. It was also suggested that one lecture is inadequate for covering such an extensive and complex topic.

Videos were included in the teaching module, and they received mixed reviews. Some felt the added little, while others thought more videos should be added. The contrasting comments may suggest that the nature of the videos used could be improved or more focused on the topic.

A particularly interesting comment was provided by a student who said s/he learned about robotics safety in a factory work environment, where safety measures were used (e.g., fences, light curtains, lockout keys). From that perspective, s/he felt that the teaching module

would be beneficial for someone who has little knowledge of robotics safety. That was despite the fact that s/he did not feel the teaching module provided a significant learning experience for her/him, as an experienced practitioner. Given the teaching module was intended to provide an introduction to robotics safety, albeit a quite detailed one, this comment is not surprising.

Conclusions

The effectiveness of a recently developed teaching module for engineers on robotic safety is assessed after it is utilized in a course setting. The various content delivery approaches (Powerpoint presentation and written document) and learning approaches (lecture and self-learning) are also assessed. The assessment of the effectiveness of the teaching module and its different utilization approaches is based on a surveying the opinions of the students who were taught using the teaching module. It is concluded that the teaching module approach is effective at promoting student learning on robotics safety, and that it provides multiple useful delivery modes – which permit students with different learning styles and preferences to take advantage of the delivery mode that suits them best.

References

Bahr, N. J. (1997). System Safety Engineering and Risk Assessment: A Practical Approach, Taylor & Francis.

Canadian Centre for Occupational Health and Safety (CCOHS). (2016). Retrieved from: http://www.ccohs.ca.

Canadian Society of Safety Engineering (CSSE). (2016). Retrieved from: http://www.csse.org.

Center for Occupational Health and Safety Engineering (COHSE). (2016). University of Michigan. Retrieved from: http://www.engin.umich.edu/dept/ioe/COHSE.

Christensen, W. C. and Manuele, F. A., Eds. (1999). Safety through Design, ASME Press.

Covello, V. T. and Merkhofer, M. W. (1993). Risk Assessment Methods: Approaches for Assessing Health and Environmental Risks, Plenum Press, New York.

DuPont Canada. (2016). Safety, Health, Environment & Energy. Retrieved from: http://www.dupont.ca/english/values/valu_shee.html.

Fullwood, R. R. and Hall, R. E. (1988). Probabilistic Risk Assessment in the Nuclear Power Industry: Fundamentals and Applications, Pergamon Press, Oxford, U.K.

Goetsch, D. L. (2001). Occupational Safety and Health for Technologists, Engineers, and Managers, 4th ed., Prentice Hall, Englewood Cliffs, NJ.

Hammer, W. and Price, D. (2000) Occupational Safety Management and Engineering, 5th ed., Prentice Hall, Englewood Cliffs, NJ.

Health Canada. (2016). Workplace Health and Public Safety Programme (WHPSP) (previously known as Occupational Health & Safety Agency (OHSA). Retrieved from: http://www.hc-sc.gc.ca.

Henley, E. J. and Kumamoto, H. (1981). Reliability Engineering and Risk Assessment, Prentice-Hall, Englewood Cliffs, NJ.

Industrial Accident Prevention Association (IAPA). (2016). Retrieved from: http://www.iapa.on.ca.

Imperial Oil. (2016). Safety Health and Environment. Retrieved from: http://www.imperialoil.ca/Canada-English/ThisIs/SHE/TI_SHE_SafetyAndHealthEnv.asp.

International Labour Organization. International Occupational Safety and Health Information Centre (CIS). (2016). Retrieved from: http://www.ilo.org/public/english/protection/safework/cis/index.htm.

Kumamoto, H., and Henley, E. J. (1996). Probabilistic Risk Assessment and Management for Engineers and Scientists, Second Edition, IEEE Press, New York.

Lawson, D. (1992). Wellness: Safety and Accident Prevention, McGraw-Hill.

Minerva Canada. (1998). Integrating Safety Management into the Curricula of Canadian Engineering Schools: Proceedings of the Safety by Design Engineering Workshop, Toronto, 20 November.

Minerva Canada. (2016). Retrieved from: http://www.minervacanada.org.

Modarres, M. (1993). What Every Engineer Should Know about Reliability and Risk Analysis, Marcel Dekker, New York.

Montgomery, J. and Kelloway, K. (2002). Management of Occupational Health and Safety, 2nd ed., Nelson, Canada.

National Institute for Occupational Safety and Health (NIOSH) (2016). Centers for Disease Control and Prevention, U.S. Department of Health & Human Services. Retrieved from: http://www.cdc.gov/niosh.

National Institute for Occupational Safety and Health (NIOSH). (2016). Engineering Education: Safety and Health Topic. Retrieved from: http://www.cdc.gov/niosh/topics/SHAPE.

Occupational Safety and Health Administration (OSHA). (2016). U.S. Department of Labor. Retrieved from: http://www.osha.gov.

Ontario Ministry of Labour. (2016). Health and Safety. Retrieved from: http://www.gov.on.ca/LAB/english/hs.

Ontario Ministry of Labour. (2016). Guide to the Occupational Health and Safety Act. Retrieved from: http://www.gov.on.ca/LAB/english/hs/ohsaguide/index.html.

Ontario Ministry of Labour. (2016). Workplace Hazardous Materials Information System (WHMIS): A Guide to the Legislation. Retrieved from: http://www.gov.on.ca/LAB/english/hs/whmis/index.html.

Ontario Power Generation, Safety. (2016). Retrieved from: http://www.opg.com/about/safety/Pages/safety.aspx.

OSH for Everyone. (2016). Retrieved from: http://www.oshforeveryone.org/wsib/default.html.

Professional Engineers Ontario (2016). Retrieved from: http://www.peo.on.ca.

Roughton, J. E. and Mercurio, J. J. (2002). Developing an Effective Safety Culture: A Leadership Approach, Butterworth-Heinemann.

Rosen, M. A. (2004). Engineering Health and Safety Module and Case Studies. Prepared for Minerva Canada, July. Retrieved from: http://www.minervacanada.org.

Scherkenbach, W.W. (1991). Deming's Road to Continual Improvement, SPC Press, Knoxville, TN.

Taylor, J. R. (1994). Risk Analysis for Process Plant, Pipelines and Transport, E & FN Spon, London.

Woodside, G. and Kocurek, D. (1997). Environmental, Safety, and Health Engineering, Wiley.

Workplace Safety and Insurance Board. (2002). Best Practices Branch, Prevention Division, Workplace Qualities Essential for Successful Health and Safety Outcomes, Ontario, October.

Workplace Safety and Insurance Board (WSIB). (2016). Retrieved from: http://www.wsib.on.ca/wsib/wsibsite.nsf/public/home_e.

Zhang D., Wei, B. and Rosen, M.A. (2016). Overview of an Engineering Teaching Module on Robotics Safety. 2016 Proc. International Conference on Mechatronics and Robotics Engineering (ICMRE 2016), Nice, France, February 18-22.

Appendix

Evaluation Form: Teaching Module on Robotics Safety

OVERALL EFFECTIVENESS

1. Overall, the module (including the Powerpoint presentation and the supplementary document) helped me understand why engineers should care about health and safety.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1
2. Overall, the module (including the Powerpoint presentation and the supplementary document) broadened my own understanding of health and safety in engineering.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1
3. I was able to understand the contents of the module.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1

EFFECTIVENESS OF MODULE COMPONENTS

4. The *Powerpoint presentation* portion of the module helped improve my understanding of robotics safety.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1
5. The *supplementary document* portion of the module helped improve my understanding of robotics safety.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1
6. The most effective way of utilizing the module would be to use only the *Powerpoint presentation*.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1
7. The most effective way of utilizing the module would be to use only the *supplementary document*.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1
8. The most effective way of utilizing the module would be to use the entire module (i.e., both the Powerpoint presentation and the supplementary document).
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1

COMPARISON OF INDEPENDENT STUDIES AND CONVENTIONAL MODES OF TEACHING

9. Compared to utilizing the module via the conventional lecture mode of teaching, utilizing the module by students in an *independent studies* manner would be more effective at facilitating learning about robotics safety.
   Strongly agree 5 5 4 3 2 1 Strongly disagree 1

EFFECTIVENESS OF EVALUATION

10. The quiz questions were a meaningful and useful way of assessing how well I learned about robotics safety through the module.
    Strongly agree 5 5 4 3 2 1 Strongly disagree 1

OTHER COMMENTS (please write these below to assist us in improving the module):