Sci Eng Ethics (2012) 18:689–697
DOI 10.1007/s11948-011-9284-0

Design, Development, and Evaluation of a Second Generation Interactive Simulator for Engineering Ethics Education (SEEE2)

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Received: 30 December 2010 / Accepted: 15 May 2011 / Published online: 2 June 2011

Abstract This paper describes a second generation Simulator for Engineering Ethics Education. Details describing the first generation activities of this overall effort are published in Chung and Alfred (Sci Eng Ethics 15:189–199, 2009). The second generation research effort represents a major development in the interactive simulator educational approach. As with the first generation effort, the simulator places students in first person perspective scenarios involving different types of ethical situations. Students must still gather data, assess the situation, and make decisions. The approach still requires students to develop their own ability to identify and respond to ethical engineering situations. However, were as, the generation one effort involved the use of a dogmatic model based on National Society of Professional Engineers' Code of Ethics, the new generation two model is based on a mathematical model of the actual experiences of engineers involved in ethical situations. This approach also allows the use of feedback in the form of decision effectiveness and professional career impact. Statistical comparisons indicate a 59 percent increase in overall knowledge and a 19 percent improvement in teaching effectiveness over an Internet Engineering Ethics resource based approach.

Keywords Engineering ethics · Training · Simulators

Introduction

The inclusion of Ethics in the engineering curriculum continues to be increasingly important for all educational institutions. This emphasis is being driven by societal pressures, accrediting organizations and state licensing agencies. Societal pressures

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include public responses to the Ford Pinto, NASA Challenger, the Hewlett–Packard, and Boeing incidents. Likewise, the Accreditation Board for Engineering and Technology (ABET) Criterion 3—Program Outcomes, requires students to be able to design systems, components, and processes within ethical constraints. Students must also attain an understanding of professional and ethical responsibility (Acceditation Board for Engineering and Technology 2010). In order to do so, engineering and technology accredited programs must include ethics within their curriculum. Similarly, state licensing agencies such as the Texas Board of Professional Engineers require the passing of a written exam on engineering ethics (Texas Board of Professional Engineers 2008). Without this knowledge, engineers cannot receive licensing. Educational institutions have addressed this need by both developing new dedicated engineering courses and modifying existing engineering courses. Institutions with engineering curriculum wide dedicated courses include Texas A&M, the University of Wisconsin, and Texas Technological University. Other institutions are forced to incorporate this material into existing introductory, seminar, or capstone courses.

A variety of specific methods have been utilized by different educational institutions to teach engineering ethics. Traditional classroom methods of teaching engineering ethics include dogma, heuristics, and case studies (Haws 2002). In the case of dogmatic approaches, students are familiarized with a pre-formulated list of do and do not activities related to the ethical practice of engineering. A slightly more sophisticated approach involves the use of simple scenarios to which the student attempts to apply the same pre-formulated ethical principles. The third approach involves the use of actual or hypothetical cases in which the student attempts to analyze the situation and provide possible courses of action. In its most effective form, students must act as actors/agents rather than observers in the ethical situation and decide whether to gather more evidence, how to raise the ethical issue, and how best to generate support for their ethical concerns (Whitbeck 1996).

Most recently, a number of organizations have sought to increase the utility of these basic approaches by improving their accessibility through the Internet. These include the development of the on-line Ethics Center for Engineering and Science Case Western University (2008), the Texas Technological University National Institute for Engineering Ethics (2008), the Texas A&M Engineering Ethics web site (2008), the ethics web site section of the National Society of Professional Engineers Ethics (2010) and others (Cummings and Lo 2004; Herkert 1997; Steneck 1999). Resources from these organizations include individual on-line courses, manuscripts, case studies, videos, DVDs, and tests for engineering ethics training. While many of these resources may be used in isolation, more effective approaches include the use of multiple forms of the above media in order to maximize the involvement of students in examining ethical situations from a broad perspective (Loui 2005).

The use of an interactive multimedia training simulator for educating students in engineering ethics was introduced by Chung and Alfred (2009). This was based on the concepts that:

- The most effective way to provide this type of realistic training would be to actually put the student in an actual situation involving engineering ethics.
- It is unrealistic and unethical to create these types of real life situations solely for the purpose of engineering ethics education.
- Simulators offer realistic training that might not otherwise be possible due to operational, cost, or time limitations

The limitation of the this first generation Simulator for Engineering Ethics Education was that it utilized a model primarily based on highly respected the National Society of Professional Engineer's (NSPE) Code of Ethics. The weakness was not with the NSPE's code of ethics per say, but with the fact that the model was based on a theoretical dogmatic approach rather than real world experiences.

Problem Statement

As innovative as the Simulator for Engineering Ethics was at the time, it was based on engineering ethics dogma rather than real world data. The lack of a mathematically driven model derived from real world data precluded the incorporation of many features that would enhance the fidelity of the simulator. In particular, the effectiveness of taking specific actions could be fed back to the user as the engineering ethical situation developed. Similarly, without real world data, it was not readily possible to account for the personal or professional impact that specific actions would have on the individual facing the ethical situation. At the time that the first generation SEEE was developed, no real world data was available that could be statistically analyzed and utilized to drive the model for the Simulator for Engineering Ethics Education. Like the first generation approach, the second generation approach is no substitute for real time, real world situations. The best educational approach would be to create real time, real world ethical situations, however, this in and of itself would be both unethical and potentially unsafe. So, this approach represents an alternative that allows for realistic interactive training within a safe educational environment.

Methodology

The second generation Simulator for Engineering Ethics Education 2.0 was developed in Authorware (Macromedia 2008). This Microsoft Windows based software facilitates the development of multimedia interactive mission critical applications that can be run over the Internet. The actual Authorware program code for SEEE2 consists of 1,028 programmable icons and 225 program variables. A sample of the Authorware code is illustrated in Fig. 1.

As with the first generation simulator, the second generation simulator also operates in four different modes. These include instructional, training, scenario, and evaluating modes. The instructional, training, and evaluating modes are similar between the first and second generation programs. The instructional, training, and

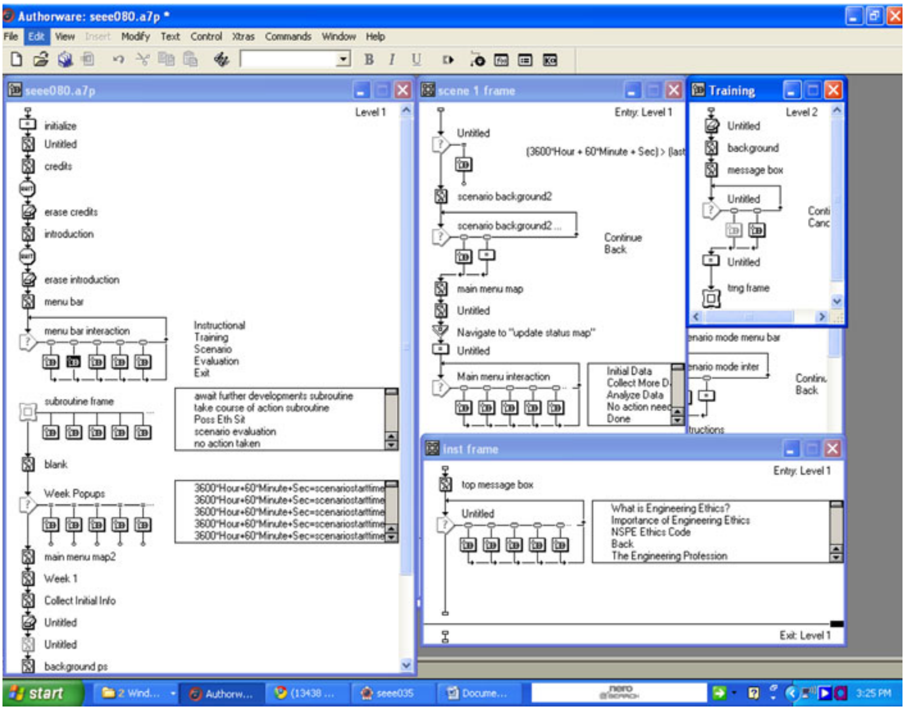

Fig. 1 Authoware code

evaluation mode are briefly summarized in the following paragraph. Readers desiring additional details on these operating modes are directed towards Chung and Alfred (2009). However, in contrast, the second generation scenario mode differs significantly from the first generation SEEE and will be described in greater detail.

In the instructional mode, users are presented with fundamental information about engineering ethics, rules of practice, and professional obligations. These follow the National Society of Professional Engineers code subjects. Fundamental Canons cover the six basic principles by which professional engineers are expected to conduct themselves. The Rules of Practice and the Professional Obligations sections elaborate on the six basic principles and provide specific examples of appropriate conduct. In the training mode, users are presented with specific limited situations involving the recognition and response to the engineering ethics subjects presented in the instructional mode. Lastly, in the evaluation mode users are provided with an objective means of assessing the level of the user's knowledge. This mode can also be used in a before and after mode to assess increased learning. There are a total of 20 randomly generated questions which are based on the National Society of Professional Engineers Ethics Code test.

As previously noted, the scenario mode differs greatly between the first and second generation simulators. The changes to the second generation scenario mode were specifically intended to overcome the limitations presented by the first generation dogma based SEEE scenario operating mode. In the second generation simulator scenario mode, the dogma approach was replaced with data obtained through the development, administration, and analysis of a survey to individuals who had been involved in an ethical engineering situation. The survey contained a total of 51 Likert agree/disagree type questions pertaining to the degree to which the individuals collected data, analyzed, responded to, effectively solved and were professionally affected by the ethical engineering situation. A total of 700 surveys were distributed to engineers identified as being knowledgeable on the subject of engineering ethics. This included professional engineers with ethics training and engineers who had published or otherwise performed work in the area of engineering ethics. A total of 56 of the 700 surveys were completed. The survey responses were refined using item remainder analysis and Cronbach's alpha. The responses to the questions were then statistically analyzed to determine cause and effect relationships by using multiple linear regression analysis. The resulting mathematical model was utilized to provide users with both the effectiveness of their decision in resolving the situation and the subsequent effect on their professional careers. While a comprehensive description of the mathematical model is beyond the scope of this manuscript, the manner in which it was implemented is illustrated in the following paragraphs.

After being presented with initial details of the scenario, the user is presented with a screen similar to that illustrated in Fig. 2. The center part of the screen is used to provide prompts to the user as they progress through the scenario. On the left side of the screen, the user is presented with different possible first level actions and second level decisions that the user may make as the ethical scenario progresses

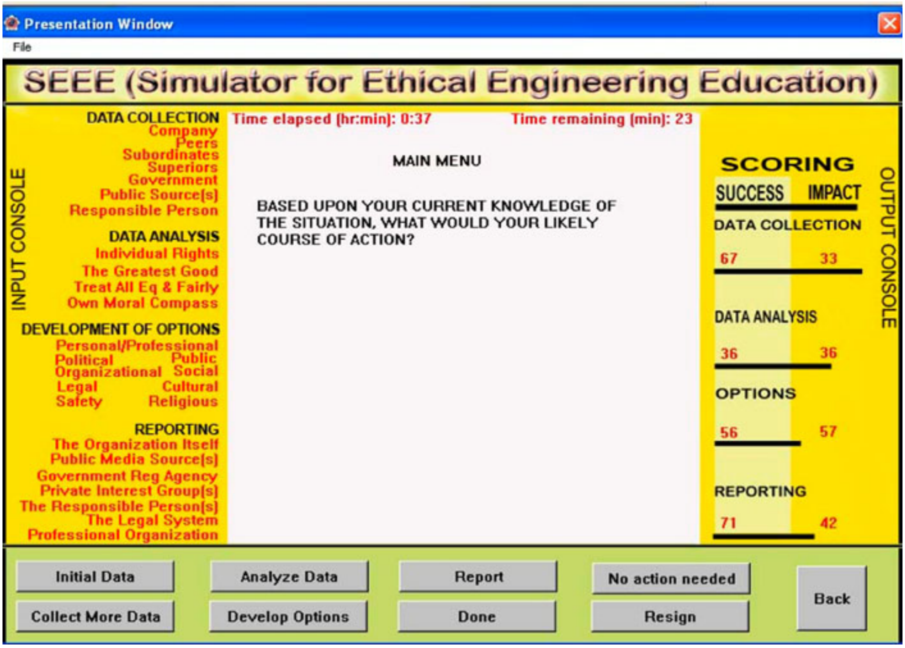

Fig. 2 Second generation SEEE simulator mode

through its life cycle. At the bottom of the screen are buttons corresponding to each of the first level actions such as collecting more data, choosing to analyze the existing data, or reporting the ethical situation. If the user elects to take a first level action then the appropriately related screen will appear allowing the user to make a second level decision pertaining on how to proceed with the first level action. For example, in the case of a first level action of collecting more data, the second level decision would be from what source to attempt to collect the additional data.

As the user progresses through the scenario and decides to take or not to take first level actions and their corresponding second level decisions, the mathematical model will continuously take the input variable value states and calculate output variable value results. The right side of the screen is updated with the results of the model's calculations. The success column indicates how successful the user is in ultimately resolving the ethical situation. The impact column indicates the degree to which the decisions have a negative effect on the individual's professional career. This component provides important immediate feedback to the user as to whether they are taking effective first level actions and making correct subsequent second level decisions. If the user is able to determine that their actions and decisions are less than desirable, they may attempt to revise their strategy for responding to the ethical situation. As the scenario progresses, the user is also presented with additional information on the scenario which may require the user to further refine their strategy. At the end of the scenario, the user is provided with final feedback on their performance.

Limited Statistical Comparison

A limited statistical comparison of the teaching effectiveness was performed between the interactive multimedia Simulator for Engineering Ethics Education and conventional web based engineering ethics education resources. The experiment was performed with a total of 43 participants. The participants were engineering students with no prior training in engineering ethics. A larger number of participants was initially sought, however, real world limitations did not allow for a larger test population. Despite the limited number of participants, statistically significant results were obtained at an alpha level of 0.05. The participants were given a known group validated 20 question pre-test on engineering ethics. The participants were then broken down into two groups of 20 and 23 with statistically equivalent mean scores on the pretest. One group received instruction by using the second generation Simulator for Engineering Ethics Education. The other group accessed a set of web sites commonly used for engineering ethics education. Following the instruction, both groups were given a post-test on engineering ethics. The test scores on a scale of 0–20 are grouped as data sets according to treatment groups and their pre- and post-test scores in Table 1. Note that in both cases, the number of participants who took the post test was less than the number from their original corresponding pretests. This is due to participant attrition between the pre and post tests.

To determine the teaching effectiveness of the second generation Simulator for Engineering Ethics, the differences in scores between the four groups were

Table 1 Summary statistics

	PREWEB	POSTWEB	PRESIM	POSTSIM
N	20	15	23	22
Mean score	9.25	12.53	9.39	14.96
Standard deviation score	2.71	2.75	2.64	2.72

statistically analyzed. Due to the limited number of participants, it was necessary to use the non-parametric Krusal–Wallis and Dunn test equivalents of the parametric ANOVA and Duncan Multiple Ranges tests.

This experiment is formally stated as:

1. Hypotheses:
   Null hypothesis: The populations are identical
   Alternative hypotheses: The populations are not identical
2. Level of Significance, alpha: 0.05
3. Criterion: Reject null hypotheses if $H = 7.841$, the value for the chi-square distribution at alpha $= 0.05$ with 3 degrees of freedom. The Krusal–Wallis H test statistic calculated using Eq. 1.
4. Calculations: Equation 1 yielded a Krusal–Wallis H test statistic of 38.33.

$$H = \frac{12}{n(n+1)}\left(\sum_{i=1}^{k}\frac{R_1^2}{n_i}\right) - 3(n+1) \tag{1}$$

5. Decision: The test statistic $H = 38.33$ which exceeds the critical value of 7.841. The null hypotheses must be rejected at a statistically significant level of 0.05. This provides evidence that one or more of the groups are statistically significantly different than the others.

With the Krusal–Wallis null hypothesis rejected, a Dunn test option in MINITAB was then performed to determine which of the data set means were statistically significantly different than each of the others at an alpha level of 0.05. The results of the Dunn test are presented in Table 2.

Discussion

The Krusal–Wallis test null hypotheses was rejected at an alpha level of 0.05. This means that one or more of the four groups is statistically significantly different. The

Table 2 Dunn test results

Groups	Z value versus critical value	Statistically significant at 0.05
PREWEB versus POSTWEB	$2.65 > 1.96$	Yes
PRESIM versus POSTSIM	$5.13 > 1.96$	Yes
POSTWEB versus POSTSIM	$2.11 > 1.96$	Yes

Dunn test then indicated that there was a statistically significant difference between the PREWEB and POSTWEB groups. This means that the use of the internet has a statistically significant effect on increased knowledge. Similarly, there was a statistically significant difference between the PRESIM and POSTSIM groups of 59 percent. However, most importantly, there is a statistically significant difference at an alpha level of 0.05 between the POSTWEB and the POSTSIM groups. This means that there is evidence to support the statement that the second generation Simulator for Engineering Ethics Education is also 19 percent more effective in teaching engineering ethics than the use of non-interactive commonly used web based resources.

Conclusion

Both Accreditation agencies such as ABET and governmental professional licensing bodies continue to emphasize the importance of ethics in the engineering curriculum. While educators cannot ethically create ethical engineering situations for educational purposes, they must still provide some sort of training. The use of dogma, heuristics, and case studies are only partially effective as they lack the interaction and feedback required for effective training. Interactive simulators such as the Simulator for Engineering Ethics can provide realistic training that might not otherwise be possible due to time, cost, or educational limitations.

The second generation Simulator for Engineering Ethics has taken this process to a more sophisticated level by replacing the interactive, but dogmatic based model approach with a new approach using a mathematical model generated from real world data. This new approach also provides the opportunity for users to receive feedback on the effectiveness of their actions and decisions and possible consequences to their professional careers. The teaching effectiveness of this approach was determined using Krusal–Wallis and Dunn tests at an alpha level of 0.05. The analysis indicated that the second generation Simulator for Engineering Ethics is approximately 19 percent more effective than utilizing existing Internet based engineering ethics resources.

Acknowledgments The authors are grateful to the Alfred P. Sloan Foundation for providing fellowship funding that helped support the development of the Simulator for Engineering Ethics Education. The authors would also thank the National Society of Professional Engineers for their permission to utilize the NSPE's code of ethics as a basis for the Simulator for Engineering Ethics Education.

References

Acceditation Board for Engineering and Technology. (2010). *Criteria for accrediting engineering programs*. http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2008-09%20EAC%20Criteria%2012-04-07.pdf.

Case Western University. (2008). On-line ethics center for engineering and science.

Chung, C. A., & Alfred, M. (2009). Design, development, and evaluation of an interactive simulator for engineering ethics education (SEEE). *Science and Engineering Ethics, 15*, 189–199.

Cummings, M. L., & Lo, J. (2004). Globalizing engineering ethics education through web-based instruction. In *IEEE International symposium on technology and society, July 17–19, 2004, Worcester, MA* (pp. 92–95).

Haws, D. R. (2002). Using the web to integrate ethics in the engineering curriculum. In *Proceedings frontiers in education conference* (Vol. 3, pp. S4F/7–S4F/12).

Herkert, J. R. (1997). Making connections: Engineering ethics on the World Wide Web. *IEEE Transactions on Education, 40*(4), 7–14. doi:10.1109/13.759672.

Loui, M. C. (2005). Educational technologies and the teaching of ethics in science and engineering. *Science and Engineering Ethics, 11*, 435–446. doi:10.1007/s11948-005-0012-5.

Macromedia. (2008). www.macromedia.com.

National Society of Professional Engineers Ethics. (2010). Web site section, http://www.nspe.org/ethics/home.asp.

Steneck, N. H. (1999, March). *Using the web for teaching engineering ethics across the curriculum.* Presented at the OEC International Conference on Ethics in Engineering and Computer Science.

Texas A&M University. (2008). *Engineering ethics*. http://ethics.tamu.edu/.

Texas Board of Professional Engineers. (2008). http://www.tbpe.state.tx.us/.

Texas Technological University, National Institute for Engineering Ethics. (2008). http://www.niee.org/pd.cfm?pt=NIEE.

Whitbeck, C. (1996). Ethics as design: Doing justice to moral problems. *The Hastings Center Report, 26*(3), 9–16. doi:10.2307/3527925.