AC 2008-150: FOSTERING ENGINEERING ETHICS PROBLEM SOLVING THROUGH COGNITIVE FLEXIBILITY HYPERTEXT: AN APPLICATION OF MULTIPLE PERSPECTIVES, MAKING CONNECTIONS AND CRISSCROSSING

Rose Marra, University of Missouri

ROSE M. MARRA is an Associate Professor in the School of Information Science and Learning Technologies at the University of Missouri. She is PI of the NSF-funded Assessing Women and Men in Engineering (AWE) and Assessing Women In Student Environments (AWISE) projects. Her research interests include gender equity issues, the epistemological development of college students, and promoting meaningful learning in web-based environments.

Demei Shen, University of Missouri

DEMEI SHEN is a doctoral candidate in Information Science and Learning Technologies at the University of Missouri. Her research interests include social computing and motivation in web-based learning.

David Jonassen, University of Missouri

DAVID JONASSEN is Distinguished Professor of Education at the University of Missouri where he teaches in the areas of Learning Technologies and Educational Psychology. Since earning his doctorate in educational media and experimental educational psychology from Temple University, Dr. Jonassen has taught at the Pennsylvania State University, University of Colorado, the University of Twente in the Netherlands, the University of North Carolina at Greensboro, and Syracuse University. He has published 30 books and numerous articles, papers, and reports on text design, task analysis, instructional design, computer-based learning, hypermedia, constructivist learning, cognitive tools, and technology in learning. He has consulted with businesses, universities, public schools, and other institutions around the world. His current research focuses on the nature of problem solving and methods for learning to solve complex problems.

Jenny Lo, Virginia Polytechnic Institute and State University

Vinod Lohani, Virginia Polytechnic Institute and State University

VINOD K. LOHANI is an associate professor in the Department of Engineering Education and an adjunct faculty in Civil & Environmental Engineering at Virginia Polytechnic Institute and State University (Virginia Tech). He received a Ph.D. in civil engineering from Virginia Tech in 1995. His areas of teaching and research include engineering education, international collaboration and hydrology & water resources.

Fostering Ethics Problem Solving in Engineering Trough Cognitive Flexibility Hypertext: An Application of Questioning as Links

Abstract

This paper describes a new computer-based learning environment, E.Y.E. (Engineering Your Ethics), to support the instruction of engineering ethics, and a study that examined the effectiveness of this environment. The online learning environment includes several engineering ethics cases and is designed to support the ill-structured nature of engineering ethics problem solving. Two versions of E.Y.E were used in first-year level engineering course; one version facilitated case analysis through hyperlinks phrased as questions (designed to encourage students to consider the relationships amongst various case elements such as the conflicting perspectives of the players and engineering ethics theories) and the other version used statement as links. We found statistically significant differences between the two groups as measured by students' analysis of an assessment case with the students who used the "questions" version of the environment outperforming the "plain link" group.

Introduction

Engineering, as a profession, involves problem solving in practice on a daily basis[1]. Most of the problems that engineers encounter in their workspace are ill-structured[2]. Ill-structured problems are those that occur in specific contexts with loosely defined problem space, vague goals and multiple answers[3]. The ethical issues that arise in the engineering workplace make engineering practices more complicated and ill-structured. Engineering ethics is "(1) the study of the moral issues and decisions confronting individuals and organizations involved in engineering; and (2) the study of related questions about moral conduct, character, policies, and relationships of people and corporations involved in technological activity" [4] (p.23).

The importance of engineering ethics is supported by the ABET[5]. EC 2000 criteria require that engineering curricula incorporate engineering ethics components[6]. Various approaches exist for training students in engineering ethics, however, all the instructional approaches retain weaknesses, including omitting the complexity of ethical issues, ignoring alternative solutions to ethical problems, and obscuring the skills for resolving engineering ethical dilemmas[7].

Ethical problems in engineering are ill-structured and complex[3]. One underlying weaknesses of the engineering ethics instructional approaches may derive from overlooking the ill-structuredness of ethical problems. Ill-structuredness means that various concepts are interrelated and these interconnection patterns may vary in each case or each problem situation[8], which causes complexity for learning and poses challenges for transfer to new situations. According to existing research[7], ignoring the complexity of ethical issues is one of the essential weaknesses.

Therefore this study implemented a learning environments (called E.Y.E. Engineer Your Ethics) to facilitate ethics problem solving at a large eastern university and investigate the effects of learning environments and factors that influence learners problem solving performance of questions as links and embedded links on ethical problem solving.

Theoretical Background

Several instructional theories and strategies comprise the theoretical and practical underpinnings of the design the engineering ethics environment.

Cognitive Flexibility Theory

One approach for instructional design and learning in complex and ill-structured domains is Cognitive Flexibility Theory (CFT) [9]. Employing the metaphor of landscape[10] to represent the ill-structured domain, CFT accentuates examining cases from different perspectives and themes to highlight the multifaceted features of each case and to establish various connections between cases, thus helping learners construct a flexible knowledge structure that can be adapted to new problem solving situations[11].

Cognitive Flexibility Hypertext (CFH hereinafter) is the hypertext designed based on CFT. Hypertext is a computer-based system that organizes information representation with interconnected links and nodes[12]. CFH can be promising for the study of engineering ethics since researchers have demonstrated that CFH environments were superior for transfer in ill-structured domains than normal hypertext environments[13].

Based on the characteristics of engineering ethics and CFT, CFH should be an appropriate medium for engineering ethics study in that it unpacks the complexity of ill-structured domain. However, in a CFH environment mainly perspectives and themes are examined. For engineering ethical issues, while perspectives of characters help identify conflict between characters in the case, and themes help understanding the issues from various ethical theories, other elements are needed to resolve ethical dilemmas. For instance, generating alternative solutions and decision-making are two components to deal with ethical dilemmas[7]. To address this, ill-structured problem solving will be incorporated to provide basic guidelines since ethical problems are ill-structured in nature.

Ill-structured Problem-Solving and Ethical Problem Solving in Engineering

Problem solving activities can be categorized into well-structured and ill-structured types[14]. Well-structured problems usually have one correct answer with fixed alternative solutions and clear goals[14, 15]. Ill-structured problems are usually context-dependent, less definable[16], and emerge in everyday practice in the form of dilemmas[14] . These characteristics of ill-structured problems make them particularly difficulty for learners to learn to solve them. Jonassen[3] argued that ethical problems were ill-structured and were categorized as dilemmas in the topology of problems.

Ill-structured problem solving is complicated and includes problem identification, solution generation, and monitoring and evaluating[17]. In the specific domain of engineering ethics, problem solving discussed in the literature involves recognizing the existing ethical dilemmas[7], grounding in ethical theories[7, 4], applying engineering codes of ethics to the specific situation[7], generating alternative solutions, and making a personal decision[7].

Design of CFH Environments and Potential Problems

Cognitive flexibility theory (CFT), ill-structured problem solving process, and the components for ethical problem solving in engineering provide a framework for the design of learning environments for engineering ethics. However, there is another potential problem associated with CFH environments, which is crisscrossing. Crisscrossing is "revisiting the same material, at different times, in rearranged contexts, for different purposes, and from different conceptual perspectives" [15, p.101]. Researchers and instructional designers posit that in the process of crisscrossing learners should acquire "interconnected, web-like knowledge structures" [9, p.170] to fit the high heterogeneity of the ill-structured domain, and acquire the ability of "situation-specific assembly" instead of "intact schema retrieval" [9, p.171]. Harvey[8] argued that a full interconnection of all elements in the CFH environments is important to improve learners' ability to transfer what they are learning in the current case to another one. Therefore, more crisscrossing has the potential to help learners deeply examine cases and obtain better knowledge transfer. However, "the prescription that learner must crisscross in the CFH is not assured in implementation" [18, p.39]; in a complex environment with random access such as CFT, learners may not understand the structure that guides their traversals[15] do not crisscross as much as expected.

Embedded links can be implemented to foster crisscrossing. Embedded links are the traditional "hyperlinks" that we have all become familiar with in using the Internet. They are links that are located *within* text or document that provide a "jump" to another web page or location; they are not arranged as a block on the right-hand, left-hand, top or bottom[19].

Although embedded links are easy to use, they may not provide a learner with sufficient queues about how the content one is currently viewing is *related* to the content one will see when one follows the link. Questions have this ability to communicate relationships, thus we proposed that creating links in the form of questions may be an improvement over simple embedded links. Since posing questions to learners can attract students' attention[20] and promote thinking that helps answer the questions[21, 22], using questions as links instead of normal links has the potential to invoke more crisscrossing, help learners understand the interconnection of concepts in CFH environments, and hence understand the ethical problem solving process. However, no empirical evidence currently exists to supports this.

Questioning

Questioning is recognized as a natural product of the learning process, and one of the most commonly used cognitive strategies to promote students' thinking[21, 22]. A question reflects the level of thought entailed to answer it and therefore they can be ranked[23]. Questioning is effective in facilitating thinking[21]. Various studies showed that questions were effective for eliciting metacognition in terms of planning and reflection in web-based learning environments[24], and that questions were effective in fostering ill-structured problem solving processes[20, 25].

Additionally, problem solving is influenced by various factors including cognitive and metacognitive factors and individual differences[20, 17]. Individual differences in terms of epistemological beliefs are discussed subsequently.

Epistemological Beliefs

Epistemology refers to the study of knowledge and sources of knowledge. Epistemological beliefs are concerned with "the nature and justification of human knowledge" [26, p.1] and are comprised of the underlying beliefs about knowledge and knowing. Although there are many theories of personal epistemology in the educational literature most developmentally-based theories agree upon a common pattern of cognitive development that progresses from simple, right-wrong thinking, through an exploration of multiple perspectives, to an understanding of knowledge and knowing that uses contextualized and reasoned choices among competing beliefs. William Perry proposed the first developmental theory of epistemology in his study of Harvard students in the 1950s [27]. His intellectual and ethical development model distinguished nine sequential positions that were classified into four categories and nine positions (Appendix A).

Epistemological beliefs have been found to relate to various learning outcomes[28, 29]. Ryan[30] found that epistemological development influenced students' conception about the coherence of paper organization, and in another study he[31] found that university students' epistemological development level influenced their standard for text comprehension in terms of knowledge or comprehension/application level of Bloom's taxonomy. Epistemological beliefs are related to learning and problem solving in that learners' existing beliefs influence their interpretation of instruction [32], and determine the set of "cognitive resources" a learner may employ in problem-solving activity[33], and influence the way learners manage to resolve ill structured problems[3].

Researchers demonstrate that different levels of epistemological beliefs play a role in learning and performance in CFH environments. Jacobson et al.[34] found that learners with a high level of epistemological beliefs learn better in a thematic crisscrossing CFH environment than those with a low level of epistemological beliefs. Mishra[35] found that the effectiveness of a CFH environment for learning chemistry depended on the epistemological beliefs of learners.

In summary, the design of CFH environments combined with the ethical problems solving guidelines is positive for fostering ethical problem solving. However, extra guidelines are necessary to foster crisscrossing. Although questioning is effective in many studies and on various tasks including ill-structured problem solving, more research is needed about whether questions as links in CFH environments are more effective than normal embedded links in promoting knowledge acquisition and transfer in ill-structured problem solving as applied to ethical issues in engineering. Epistemological beliefs may play a role in influencing students' learning in problem solving in CFH environments, or may have an interaction effect with the two types of links. To examine the effects of different links in CFH learning environments and the influence of epistemological beliefs on ethical problem solving, the following research questions will be examined.

1. Overall, do students who use the CFH environments with questions as links and embedded links have different levels of ethical problem solving performance in terms of question generation and case analysis?
2. Do students' epistemological beliefs influence their problem solving performance in terms of the case analysis essay in CFH environments?

Method

Description of CFH Learning Environments – E.Y.E – Engineer Your Ethics

E.Y.E was designed based on CFT[8], ill-structured problem solving process [3, 17], and guidelines for engineering ethics learning[7]. The objective of the learning environment is to promote knowledge transfer and crisscrossing to enhance ethical problem solving. There are two versions of E.Y.E. One uses with normal embedded links, and the other uses questions as links. Our study investigates how the difference in these link types influences students' abilities to solve ethics cases.

<u>Common Features of the two learning environments</u>

Each of the two versions of E.Y.E contain a total of four engineering ethics cases and one survey on student beliefs about knowledge and learning. All the cases represent various ethical dilemmas in engineering, and the survey examines the epistemological development of students. Two of the cases are for teaching how to solve engineering ethics problems. Embedded links or questions as links for crisscrossing are provided. Answers are provided for each link/question as well (Figure 1).

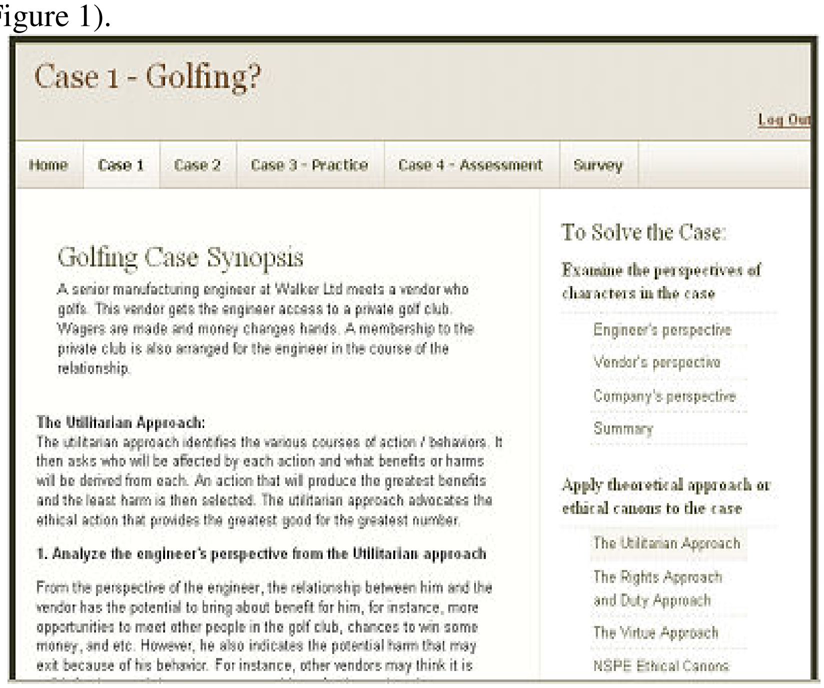

Figure 1. A Teaching Case in E.Y.E.

The third case (figure 2) is for students to practice what they have learned in the first two cases. The practice case is examined in the same way as the teaching cases are, but no answers are provided. As shown in Figure 2, a text box is provided and students are asked to do their own analysis of the case based on what they have learned in the cases 1 and 2 and then enter their answers to questions that are asked. Students received feedback on their answers in the form of expert answers that were provided when students submitted their answers.

Figure 2. Practice Case in E.Y.E.

The fourth and final case is for assessment, and participants are asked to write a case analysis essay to describe how they would resolve the provided case. Students responded to a short series of questions which required them to both propose and justify their solution. The research team used their case analyses (in the form of short essays) to measure their engineering ethics problem solving ability. Completing the assessment case was a required and graded portion of the course.

For the teaching cases and the practice case, there are four categories of links on the right hand side of the screen (see Figure 3), which indicate how to examine and resolve the case. The links include 1) Examine the perspectives of characters in the case, 2) Apply theoretical approach or ethical canons to the case, 3) Generating solutions, and 4) Decide upon a "best" solution. Following the links helps students apply a problem solving process to the case.

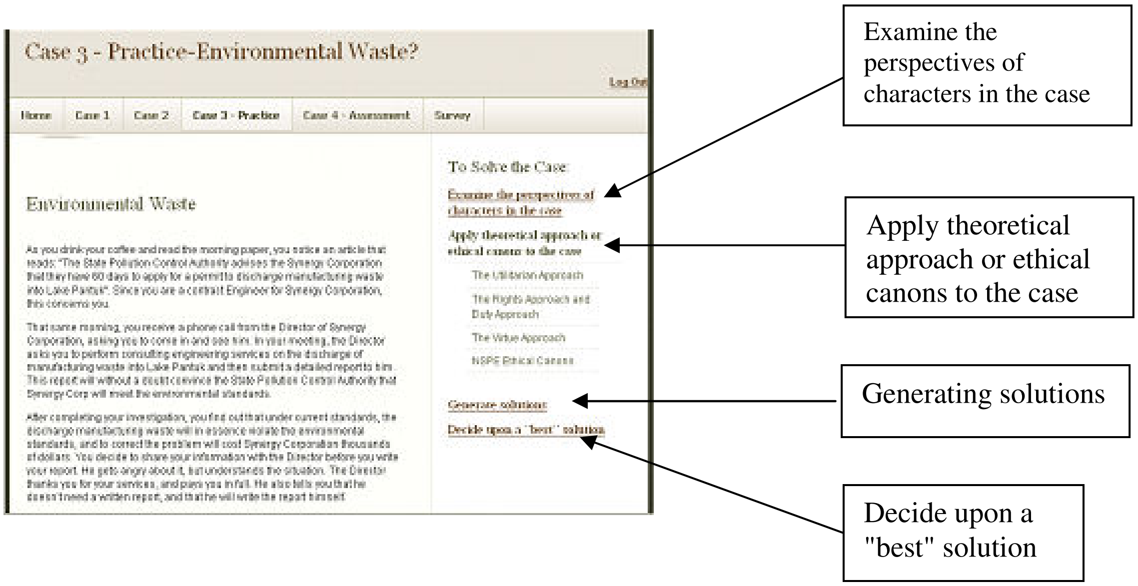

Figure 3 Engineering Ethical Problem Solving in E.Y.E. Environments

Differences between the Two Versions of E.Y.E.

Embedded links (Figure 4) are used to foster crisscrossing in one environment, and the questions as links (Figure 5) are employed in the other environment to promote crisscrossing by attracting student's attention[20] and promoting a high level of cognitive process with higher order questions[23].

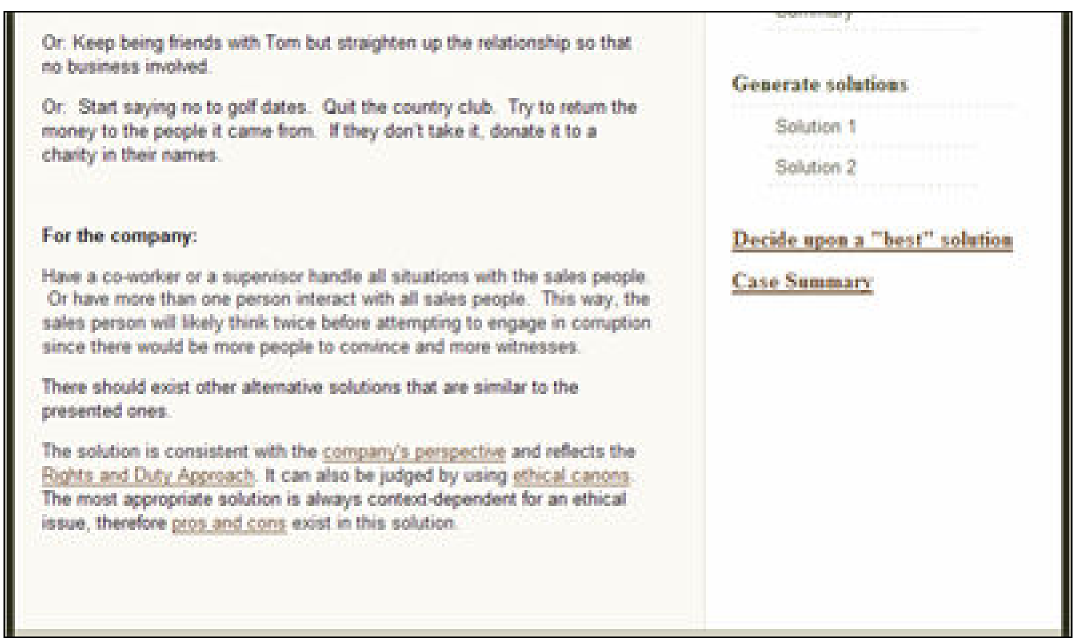

Figure 4: Embedded links in E.Y.E.

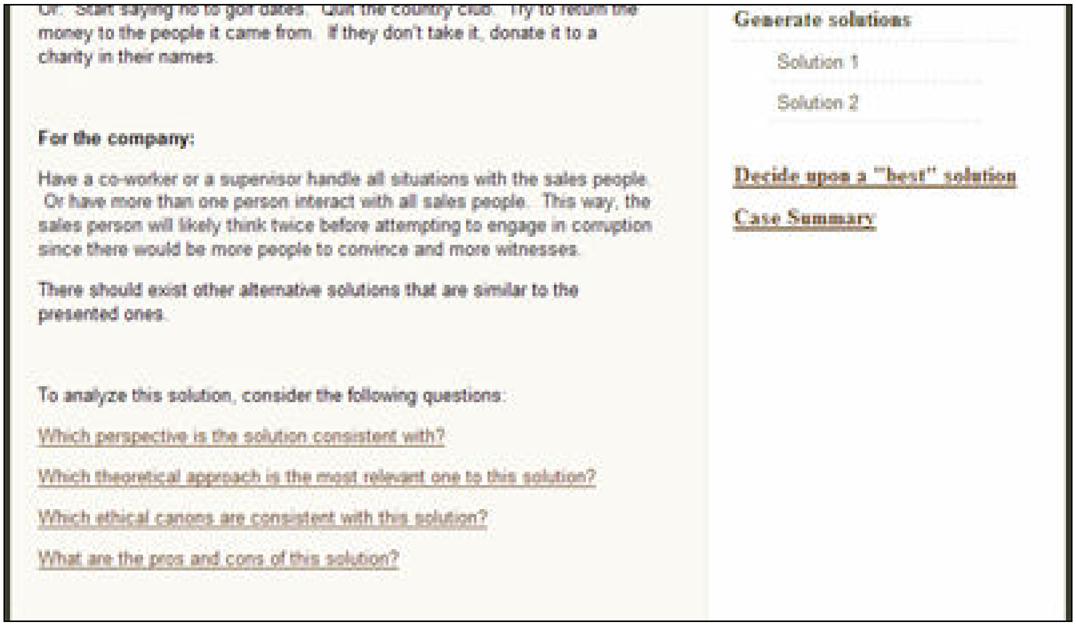

Figure 5: Questions links in E.Y.E

There is a one-to-one mapping between the two versions of the environment for embedded links and questions as links. Both of the environments are designed to foster in-category crisscrossing – that is they are designed to foster linking within the components of the problem solving process (e.g. comparing perspectives, theoretical approaches, and solutions). They are also both designed to support cross-category crisscrossing, which is the process of connecting various components of ethical problem solving, such as linking perspectives to theoretical approaches, reasoning solutions based on perspectives and theories, etc.

The questions used as links were designed by the researcher based on the ethical problem solving guidelines[7], Bloom's Taxonomy[36], and the crisscrossing feature in CFT. Hipp[7] proposed that ethical problem solving should include theories, facts of the case, codes of ethics, solutions, and personal decisions. Bloom's taxonomy indicates higher order cognitive processing is stimulated by higher levels of questions[37]. CFT requires reexamining the case from a different route. The questions are designed to foster higher level thinking in the crisscrossing process that examines the perspectives, theories, canons, solutions and decisions. Table 1 displays the embedded links and questions as links in the two versions of E.Y.E. from a portion of case 1. Similar embedded links and questions as links are used in case 2.

Table 1 Embedded Links and Questions as Links in E.Y.E. Environments

Embedded links in one CFH learning environment	**Questions as links in the other CFH learning environment**

This perspective can be compared to the Vendor's perspective and compared to the Company's perspective. Also, it can be analyzed from the Utilitarian Approach, the Rights Approach and Duty Approach, and the Virtue Approach. Additionally, it can be examined based on ethical canons.	To understand the perspective better and see how it helps you to resolve the case, here are some questions you should think about and explore. Take a minute to come up with your own answers before following each link: • How does the engineer's perspective compare to vendor's perspective? • How does the engineer's perspective compare to company's perspective? • How does the Utilitarian Approach apply to this perspective? • How do the Rights Approach and Duty Approach apply to this perspective? • How does the Virtue Approach apply to this perspective? • How does the engineer's perspective reflect/violate the ethical canons?

Context of Study and Participants

The study was conducted in a 2-credit hour course, Engineering Exploration at an eastern United States university. The course lasts one semester and is one of the required courses for first-year engineering students. The purpose of the course is to introduce first-year engineering students "to the profession and various engineering departments within the College of Engineering". It includes "foundation material in: problem definition, solution and presentation; design, including hands-on realization working in teams; modeling and visual representation of abstract and physical objects; scientific computation; algorithm development, computer implementation and application; documentation; ethics; professionalism" [38, p.2]. The portion of the course that the present study focuses on is a two to three week course unit on engineering ethics, which aims to provide an introduction of engineering ethics to students[38].

Participants for this study were students in one of the lecture sections of the course. The faculty member who taught the lecture has had several years' of experience teaching the course. In addition to a weekly lecture (of approximately one hundred and fifty students total), students attend a smaller weekly hands on session called a "workshop". There were five workshops for the students in the lecture section that we studied; each workshop section is facilitated by graduate teaching assistants and includes about thirty students.

Participants were divided into two groups by intact workshops and used one of two versions of a CFH learning environments, the E.Y.E.. Students in three workshops were assigned to the group 1 which used the CFH environment with questions as links for crisscrossing, and students in the other two workshops were assigned to group 2 that used the CFH environment with embedded links for crisscrossing. All participants in the two groups had the same classroom lecture from the same instructor. Table 2 reports the demographic information of the final sample of participants in the two groups.

Table 2. Demographic information for 123 participants in 2 groups

Demographic information		Number of participants	Percentage (%)	Total respondents
Group 1: Question Link group				
Gender	Male	60	87.0	69
	Female	9	13.0	
Ethnicity	Asian & Pacific American	5	7.2	69
	White American	62	89.9	
	Foreign National on student visa	1	1.4	
	Foreign National/U.S. Resident (green card)	1	1.4	
School Year	First-year student	66	95.7	69
	Second-year student	3	4.3	
Group 2: Embedded Link group				
Gender	Male	41	75.9	54
	Female	13	24.1	
Ethnicity	Asian & Pacific American	3	5.8	52
	White American	49	94.2	
School Year	First-year student	53	98.1	54
	Second-year student	1	1.9	

Procedure

Subjects participated in the study during a three-week section of the course on engineering ethics. At the first class lecture for the ethics unit, students watched a training video that introduced the learning environments and what they can learn from them. Students were also given an instructional page that contains the URL for his or her assigned version of the E.Y.E. environment, written instructions on how to sign up and log in to the learning environment, and what they should do to complete the learning tasks in the environment. The URL directs students to the webpage where they can sign up with their user name, password, full name, and email address. Once they completed their registration, they received an email containing their user name and password.

Participants were asked to go through the content of the learning environment and complete the activities in three weeks (the ethical learning module lasts three weeks). Participants were instructed to complete the teaching cases and the practice case in the first two weeks. Participants were then told to complete the assessment case and upload their answers (case analysis essay) to the server in the last week. They also completed an epistemological development survey during the three week period.

Measures and Instruments

Outcome Variables

To assess students' ethical problem solving skills, case four in the E.Y.E environment served as an engineering ethical assessment case. To control the amount of time students spent on the case, the case became available towards the end of the three-week unit on ethics and students were given a completion deadline. Students were allowed one week to complete the assessment case.

For the assessment case, students were asked to write an essay to propose and justify a solution for the case. In the essay that analyzes and resolves the assessment case, students need to identify the perspectives of stakeholders, apply various ethical theories and ethical canons to the case, generate alternative solutions, and make a personal decision. A rubric (Appendix B) was used to assess their problem solving performance on the case analysis essay. The maximum score is 20.

Independent Variables

Independent variables in the present study include students' use of one of the two different CFH environments, and students' epistemological development scores.

Measures of Epistemological development

Epistemological development was measured with the Learning Environment Preferences (LEP) instrument[39]. The LEP is an objective measure for the Perry scheme of intellectual development. It asks participants to rate the importance of sixty-five items based on a 1-4 Likert scale with 1 indicating not at all significant and 4 indicating very significant. The sixty-five items examine participants' beliefs about their ideal learning environments from five domains, including course content, role of instructors, role of peers, classroom atmosphere, and evaluation procedure. In addition, participants are asked to rank three most important items in each domain. The five domains "focus on student preferences for specific aspects of the classroom learning environment shown to be associated with increasing complexity on the Perry scheme of intellectual development" [40, p.5]. The LEP measures produces a "cognitive complexity index" (CCI) resulting in four Perry positions of 2 to 5. Position 1 was excluded because it had not been "empirically verified", while position six through nine "can best be captured by qualitative research methods" [40,p.6]. The CCI ranges from 200 to 500 and maps to Perry positions of intellectual development as follows:

- position 2 (dualism): 200-274
- position 3 (early multiplicity): 275-349
- position 4 (late multiplicity): 350-424
- position 5 (approaching contextual relativism): 425-500

The original Cronbach's coefficient alphas for these four positions ranged from .72 to .84[39] and the test–retest reliability was .89[39]. It takes about 30-45 minutes for participants to complete the survey.

Data Analysis and Results

Epistemological Development

Participants' epistemological development level, when measured by the CCI score, ranged from 223 to 428. Table 3 shows the statistics of epistemological development of all participants. The higher the CCI scored, the more advanced epistemological development level the participants had. The data showed that participants' epistemological beliefs ranged from position 2 to position 5, which indicates that participants' beliefs about knowledge ranged from regarding knowledge as right or wrong to taking knowledge as contextual, and their beliefs of learning ranged from regarding learning source or answers are from authorities to people can learn with their methods.

Table 3: Epistemological Development (LEP) Results for Participants

Group (N)	Overall Minimum	Maxi mum	Mean	Position 2	Position 3	Position 4	Position 5
Question Link (54)	223	407	317.46	12	41	16	0
Embedded Link (69)	233	428	332.69	6	26	21	1
Combined (123)	223	428	324.15	18	67	37	1

To examine if the two groups differ significantly on participants' epistemological development, an independent samples t-test (Table 4) was conducted. The result found no statistical difference between the Question Link group (M = 317.46, SD = 44.05) and Embedded Link group (M = 332.69, SD = 43.95), t (121) = -1.90, $p > .05$. This result confirms that the two groups are beginning with approximately the same epistemological beliefs and this should not interfere with any differences in performance on case analysis between the two E.Y.E groups.

Table 4: Independent samples t-test between Question Link group and Embedded Link group on Epistemological Development

		N	**Mean**	**SD**	**Difference**	***t***	**Sig.**
Epistemological Development	Question Link Group	69	317.46	44.05	-15.22	-1.90	.059
	Embedded Link Group	54	332.69	43.95			

Participants' Problem Solving Performance on Case Analysis

We measured participants' problem solving performance from their case analysis essay. A holistic rubric (Appendix B) was used to assess the case analysis essays. The rubric includes five categories and focuses on the main components of ethical problem solving processes, including identifying main characters' perspectives, applying theories to perspectives, applying ethical canons to perspectives, generating multiple solutions based on previous analyses, and making a decision about how to solve the case. Each case essay was evaluated by aligning it to the five categories of the rubric. Each was assigned a score from 0 to 4 for every category; hence the total possible score for one individual essay is 20.

An independent samples t-test was performed to examine if differences existed between the two groups using the two learning environments (Table 5). The result found statistical differences between the Question Link group (M = 15.66, SD = 4.66) and Embedded Link group (M = 12.70, SD = 5.50), t (121) = 3.23, $p < .01$. The result indicated that participants who used the two different environments performed significantly different on their case analysis essay.

Table 5: Independent samples t-test between Question Link group and Embedded Link group on Case Analysis Essay

		N	Mean	SD	Difference	*t*	Sig.
Case Analysis Essay	Question Link Group	69	15.66	4.66	2.96	3.23	.002
	Embedded Link Group	54	12.70	5.50			

Participants' Epistemological Development and Problem Solving Performance on Case Analysis

Because significance differences existed between the performances of participants in the two groups, two sets of simple linear regression were conducted with CCI as the independent variable and student performance on case analysis essays as the dependent variable for each group. CCI was not a significant predictor of essay performance for either the Question Link or the Embedded link groups, $F(1, 67)=2.15$, $p>.05$, and $F(1, 52)=.53$, $p>.05$, respectively (see Table 6).

Table 6: Regression analysis for CCI predicting performance in two groups

Variable	B	SE *B*	β	t	R^2	A*dj* R^2	F
Performance							
CCI (Question Link Group)	-.02	.01	-.18	-.1.47	.03	.02	2.15
CCI (Embedded Link Group)	-.01	.02	-.10	-.73	.01	.02	.53

Discussion

The aim of the present study is to examine the effects of cognitive flexibility learning environments with questions as links and embedded links and the influence of epistemological development on ethical problem solving in engineering. The findings demonstrated that participants in the question link group performed significantly better than those who used the embedded link environment, while epistemological development was not a significant predicator for problem solving performance for either group.

The finding indicated that question links were more effective in fostering participants' ethical problem solving performance in engineering. Prior studies have also shown that questioning was effective in facilitating thinking[21], eliciting metacognition in terms of planning and reflection in web-based learning environments[42], and fostering ill-structured problem solving processes[20]. The finding from the present study is consistent with the previous research, and expanded research in problem solving of engineering ethics in a web-based environment.

Regarding epistemological development, participants in the two groups mainly clustered in position 3 and position 4. The regression analysis indicated that participants' epistemological development was not an influential factor in their problem solving performance. Epistemological beliefs is people's basic assumption about knowledge and how learning occurs, however, other factors may play a role to influence participants' problem solving performance in engineering ethics, such as motivation. Additionally, engineering ethics problems are ill-structured and complicated. Cognition and metacognition are important factors that influence ill-structured problem solving [17, 20]. In the current study, the participants were mostly first-year college students. For these students domain specific knowledge, structural knowledge, and learning strategies that make up one's metacognition may be more important than epistemological beliefs and affect their performance in solving ethical problems. More research on examining students' other characteristics such as motivation, learning strategies, etc. that may be key in solving ill-structured problems is necessary.

The findings from the study have both theoretical and practical implications. Theoretically, the study broadens research in engineering ethics and implied that solving engineering ethics problems from the perspective of ill-structured problems solving is feasible. Practically, the study verified that questioning might be an efficient instructional strategy that helped provoke students' thinking and foster their ill-structured problem solving in engineering ethics. This study is unique from this point since no other studies have shown these outcomes. No study is without limitations; that limited sample size is a limit of this study. Data were collected from about one hundred and twenty students and the result may not generalizable. In addition, the study was conducted in web-based environments, while some students may prefer traditional learning environments. This may influence the result of the study and increase the complexity when interpreting the results.

References

1. Lynch, W. T. & Kline, R. (2000). Engineering practice and engineering ethics. *Science Technology Human Values, 25*, pp. 195-225.
2. Jonassen, D. H., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95* (2), 139-148.
3. Jonassen, D. H. (2000). Toward a Design Theory of Problem Solving. *Educational Technology Research and Development, 48* (4), 63-85.
4. Martin, M. W., R. & Schinzinger, R. (1996). *Ethics in engineering*. 4th ed. New York: McGraw-Hill.
5. ABET (Accreditation Board for Engineering and Technology). Retrieve March 2007 from: http://www.abet.org/
6. ABET Criteria for Accrediting Engineering Programs (1997). Retrieve March 2007 from: http://www.ie.metu.edu.tr/download/criteria.pdf
7. Hipp, C. (2007). An integrative approach to teaching engineering ethics. *Proceedings of American Society for Engineering Education*, Hawii.
8. Spiro, R.J., Coulson, R.L., Feltovich, P.J., & Anderson, D. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In V. Patel (ed.), Proceedings of the 10th Annual Conference of the Cognitive Science Society. Hillsdale, NJ: Erlbaum.
9. Spiro, R. J. & Jehng, J. C. (1990). Cognitive flexibility and hypertext: Theory and technology for the non-linear and multi-dimensional traversal of complex subject matter. In D. Nix & R. J. Spiro (Eds.), *Cognition, education, and multimedia: Explorations in high technology*. Hillsdale, NJ: Lawrence Erlbaum.
10. Wittgenstein, L. (1953). *Philosophical investigations*. New York: Macmillan.

11. Spiro, R. J., Vispoel, W., & Schmitz, J. G. (1987). Knowledge acquisition for application: cognitive flexibility and transfer in complex content domains. In B. K. Britton & S. M. Glynn (Eds.) *Executive control processes in reading*. Hilsdale, NJ.
12. McKnight, C., Dillon, A. & Richardson, J. (1996) *User centered design of hypertext and hypermedia for education*, in Jonassen, David H., Eds. *Handbook of Research on Educational Communications and Technology*, pages pp. 622-633. New York: Macmillan.
13. Jacobson, M. J. & Spiro, R. D. (1995). Hypertext learning environments, cognitive flexibility, and the transfer of complex knowledge: An empirical investigation. *Journal of educational Computing Research, 12* (4), p. 301-333.
14. Jonassen, D. (1997). Instructional design model for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research and Development 45*(1), 65-95.
15. Spiro, R. J., Feltovich, R. P., Jacobson, M. J., & Coulson, R. L. (1992). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. M. Duffy, & D. H. Jonassen (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 57--76). Hillsdale, NJ: Erlbaum.
16. Shin, N., Jonassen, H. D., & McGee, S. (2003). Predictors of well-structured and ill-structured problem solving in an astronomy simulation. Journal of Research in Science Teaching, 40(1), 6-33.
17. Hong, NS. (1998). The relationship between well-structured and ill-structured problem solving in multimedia simulation. Ph.D. Dissertation of Pennsylvania State University.
18. Harvey, D. H. (1999). Investigations of cognitive flexibility hypertexts: from theory to application. Unpublished Doctoral Dissertation, The Pennsylvania State University.
19. Bernard, M., Hull, S., & Drake, D. (2001). Where Should You Put the Links? A Comparison of Four Locations. Usability News 3 (2) retrieved Jan.2008: http://psychology.wichita.edu/surl/usabilitynews/3S/links.htm
20. Ge, X., & Land, S.M. (2003). Scaffolding students' problem-solving processes in an ill-structured task using question prompts and peer interactions. *Educational Technology Research & Development, 51* (1), 21-38.
21. Clasen, D. R. & Bonk, C. (1990). Teachers tackle thinking. Madison, Wis: Madison Extension program.
22. Tinsley, D. C. (1973). Use of questions. *Educational Leadership, 30* (8), 710-713.
23. Dori, Y. J. & Herscovitz, O. (1999). Question-posing ability as an alternative evaluation method: Analyses of an environmental case study. *Journal of Research in Science Teaching, 36* (4), p. 411-430.
24. Davis, E. A., & Linn, M. (2000). Scaffolding students' knowledge integration: Prompts for reflection in KIE. *International Journal of Science Education, 22*(8), 819–837.
25. Ge, X., & Land, S.M. (2004). A conceptual framework for scaffolding ill-structured problem solving using question prompts and peer interactions. *Educational Technology Research & Development, 52* (2), 5-22.
26. Hofer, B. K. & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of educational Research, 67* (1), pp. 88-140.
27. Perry, W. G. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* New York: Holt, Rinehart and Winston.

28. Davis, E. (1997). Students' epistemological beliefs about science and learning. Paper presented at the annual meeting or the American Educational Research Association, Chicago.
29. Schommer, M. & Dunnul, P. A. (1997). Epistemological beliefs of gifted high school students. *Roeper review, 19* (3), 153-156.
30. Ryan, M. P. (1984). Conceptions of prose coherence: individual differences in epistemological standards. *Journal of Educational Psychology*, *76* (6), 1226-1238.
31. Ryan, M. P.(1984). Monitoring text comprehension: individual differences in epistemological standards. *Journal of Educational Psychology*, *76* (2), 249-258.
32. Hofer, B. (2001). Personal epistemology research: Implications for learning and instruction. *Educational Psychology Review, 13*(4), 353-382.
33. Schoenfeld, A. H. (1983). Beyond the purely cognitive: Belief systems, social cognitions, and metacognitions as driving forces in intellectual performance. *Cognitive Science, 7*, 329-363.
34. Jacobson, M. J., Maouri, C., Mishra, P., & Kolar, C. (1996). Learning with hypertext learning environments: theory, design, and research Source. *Journal of Educational Multimedia and Hypermedia, 5* (3/4), 239-281.
35. Mishra, P. (1998) *Learning complex concepts in chemistry with multiple representations: Theory based design and evaluation of a hypertext for the periodic system of elements*. Unpublished dissertation, University of Illinois at Urbana-Champaign.
36. Bloom, B. S. (ed.) (1956) *Taxonomy of Educational Objectives, the classification of educational goals? Handbook I: Cognitive Domain* New York: McKay.
37. Wisher, R.A., & Graesser, A.C. (2005). Question asking in advanced distributed learning environments. In S.M. Fiore and E. Salas (Eds.), *Toward a science of distributed learning and training*. Washington, D.C.: American Psychological Association.
38. Lo, J. Lohani, V. & Mullin, J. (2007). Introduction of contemporary engineering ethics issues in a freshman-engineering course. Proceedings of ASEE Annual Conference, Honolulu, Hawaii.
39. Moore, W.S. (1989). The Learning Environment Preferences: Exploring the construct validity of an objective measure of the Perry scheme of intellectual development. *Journal of College Student Development, 30*, p. 504-514.
40. Moore, W. S. (1988). The learning environment preferences: an instrument manual.
41. Jonassen, D.H., Marra, R.M., & Palmer, E. (2003)."Epistemological Development: An Implicit Entailment of Constructivist Learning Environments". In Seel, N.M., & Dijkstra, S. (Eds.), *Curriculum, Plans and Processes of Instructional Design: International Perspectives* (pp. 75-88). Mahwah, NJ: Lawrence Erlbaum.
42. Davis, E. A., & Linn, M. (2000). Scaffolding students' knowledge integration: Prompts for reflection in KIE. *International Journal of Science Education, 22*(8), 819–837

Acknowledgement

The authors would like to acknowledge the National Science Foundation Grant #DUE-0618459 that provided funding for this project.

Appendix A. Perry's scheme of epistemological development[41, 27]

Perry Category	Perry Position	Knowledge	Learning
Dualism	1 – Basic Dualism (hypothetical)	Knowledge is right or wrong, a collection of facts.	Receive right answers from authority.
	2 - Multiplicity Pre-legitimate	Knowledge is generally right or wrong. Complexity or uncertainty is either an error or a teaching tool.	Authorities are the source of right answers or give us problems so we can learn to find the Truth.
Multiplicity	3 - Multiplicity Legitimate but Subordinate	Knowledge is right or wrong, and some knowledge is unknown temporarily.	Authority is the source of answers or the source of method to find the answers.
	4 - Multiplicity	Some knowledge is right or wrong, but most is not yet known. Where authorities do not know, everyone is entitled to their own opinion.	Authorities are the source of ways to think.
Relativism	5 - Contextual Relativism	Most knowledge is contextual and can be judged qualitatively.	Student learns methods and criteria of their discipline. Metacognition begins.
	6 - Commitment Foreseen	Knowledge is not absolute but student accepts responsibility for making judgments.	Student accepts responsibility for making a commitment based on their values.
Commitment within Relativism	7, 8 and 9- Commitment within Relativism	Commitments made within a relativistic world as an affirmation of one's own identity.	Choices made in the face of legitimate alternatives and after experiencing genuine doubt.

Appendix B. Rubric for evaluating the essay answer to the assessment case

Category / Score	0-1.0	1.1-2.0	2.1-3.0	3.1-4.0
Identifies important	Identify some	Identifies some	Identifies most	Identifies all the

perspectives	perspectives inaccurately or fails to identify any perspectives of characters in the case	of the perspectives of the characters in the case accurately	of the perspectives of the characters in the case accurately	main perspectives of the characters in the cases accurately
Application of theories to perspectives	Demonstrate little or no understanding of ethical theories	Demonstrate understanding of applying ethical theories, but understanding is partial or flawed or explanation is incomplete or inaccurate or may not relate to the case	Demonstrate general understanding of ethical theories through some discussion of the application to the case	Demonstrate overall understanding of ethical theories through accurate discussion of the application to the case
Application of ethical canons to perspectives	Fails to identify any ethical canons for the cases.	Identifies ethical canons that are irrelevant to the case	Identifies partial ethical canons relevant to the case accurately	Accurately identifies ethical canons to resolve the cases
Solutions: Application of theories; violation/consistency to perspectives, theories, canons; discuss pros and cons of solutions	Provide inaccurate or no alternative solutions.	Provide alternative solutions that are irrelevant to the case	Provide alternative solutions based on partial application of theories and ethical canons	Provide alternative solutions based on previous application of perspectives, theories, and ethical canons
Decision justification	Does not make a decision when resolving the case	Make decisions that are not based on ethical theories, ethical canons, solutions, and pros and cons of solutions.	Make decisions based on some of the elements including ethical theories, ethical canons, solutions, and pros and cons of solutions, but not all the elements are considered.	Make decisions based ethical theories, ethical canons, solutions, and pros and cons of solutions.