AC 2012-5074: PROMOTING SECOND-YEAR ENGINEERING STUDENTS' EPISTEMIC BELIEFS AND REAL-WORLD PROBLEM-SOLVING ABILITIES THROUGH CASE-BASED E-LEARNING RESOURCES

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Promoting Second-Year Engineering Students' Epistemic Beliefs and Real-World Problem-Solving Abilities Through Case-Based E-Learning Resources

Abstract

The purpose of this project is to design, develop, and validate a case-based e-learning module that promotes the development of second-year engineering students' epistemic beliefs as well as the development of their abilities to deal with real-world, ill-defined engineering problems. Thirty-one second-year engineering students vicariously experienced real-world problems through a case-based e-learning module that consists of four major phases: exploring situations, constructing reality, creating solutions, and reflecting on the product and the process. The changes of students' problem-solving skills as well as their epistemic growth were measured and analyzed. The results reveal that students' problem-solving performances were improved when they were guided through the four phases of learning activities in the module. However, their guided problem-solving abilities failed to transfer to solve another problem without guidance. With regard to their epistemic growth, no change was observed after their completion of the learning activities in the module. The implications of designing a case-based e-learning environment to develop students' problem-solving skills as well as to facilitate their epistemic growth are discussed.

Introduction

Uncertainty is one of the most important characteristics of real-world problems that we experience our daily lives.[1] Real-world problems are often made up of complex situations surrounded by multiple perspectives among different stakeholders. They have diverse solutions along with multiple criteria for evaluating the tentative solutions.[1-6] Dealing with these uncertain, ill-defined problems requires fundamentally different skills and attitudes than those necessary for dealing with well-defined problems that have clear goals and known rules and solutions.[2,4,5] It is important to provide college students with proper educational experiences so they can develop necessary skills and attitudes to deal with uncertain, ill-defined problems they will encounter in society.

Role of Epistemic Stages in Solving Real-World Problems

One important factor that influences human learning and performance in solving ill-defined problems is one's personal epistemic belief.[4,7-9] Personal epistemic beliefs mean one's beliefs about knowledge, knowing, and learning[10] and reflect personal beliefs about what knowledge is, "how knowledge is constructed, how knowledge is evaluated, where knowledge resides, and how knowing occurs."[10 (p4)] This belief system determines one's way of approaching the learning process, evaluating information, constructing new knowledge, building arguments, creating solutions, and making decisions in a complex, undefined problem space.[7-9] Recent empirical studies indicate that students' personal epistemology plays a critical role in solving unclearly defined, complex problems. Kitchener[3] initially verified that unclearly defined problems require epistemic monitoring skills while well-defined problems require only cognition and metacognition, as confirmed by later studies.[4,8] Perry[7] began to question why college students responded to similar learning environments differently and found that an individual's different epistemic stage plays a crucial role in organizing his/her learning process and dealing with unclearly defined problems. Perry's original nine stages of epistemic development have been refined as four major stages:[11] dualism (black-and-white types of thinking and their variations), multiplicity (acknowledging uncertainty and accepting multiple opinions), contextual relativism (acknowledging the importance of contexts for meaning making), and commitment within relativism (adding ethical and moral responsibility and professional commitments to contextual relativism).

Challenges of Second-Year College Students in Their Epistemic Growth

Second-year college students are placed in an important stage in Perry's intellectual and ethical development scheme[7] and King and Kitchener's reflective judgment model.[8] According to Perry's epistemic development scheme,[7,11] second-year students are in the process of moving from dualism (black-and-white type of thinking) to the multiplicity stage by acknowledging uncertainty and accepting multiple opinions.[12] King and Kitchener's reflective judgment model[8] has three major stages, pre-reflective, quasi-reflective, and reflective thinking. Second-year college students are usually placed in the later stage of pre-reflective thinking (believing that knowledge is certain) and are about to move to the early stage of quasi-reflective thinking (acknowledging uncertainty in problems and knowledge). Thus, their approaches to problem solving and learning are significantly different among these epistemic stages.

Successful engineers should be open to acknowledging and embracing diverse perspectives from different stakeholders and disciplines. They also need to critically reflect upon basic theoretical assumptions and their problem-solving process while assessing problem situations and creating possible solutions. Their decisions and judgments should be based on their scientific knowledge and ethical responsibilities as well as professional commitments. We believe that engineering students' position in the spectrum of personal epistemic beliefs, especially during their college years, will play a significant role in shaping their approaches to organizing their learning process and building their expertise. Their epistemic growth will also help them in dealing with unclearly defined real-world engineering problems in the same manner that an engineer can reasonably disagree with another engineer's opinion on identified problems or proposed solutions.

Pedagogical Model and the Interface of the Case-based E-Learning Module

Choi and Lee[12] conducted a four-year iterative empirical study in a second-year teacher education course in order to develop a case-based e-learning environment model for promoting students' epistemic development and ill-defined problem-solving abilities. This study confirms that most of the second-year teacher education college students are at the late stage of dualism (or late stage of pre-reflective thinking), where they tended to simplify situations from a single perspective. Choi and Lee's case-based e-learning environment promoted the second-year college students from upper dualism to lower multiplicity after only a three-week implementation.[12] This growth would have required a longer period of time, from several months to a year.[8]

Based on the modification of Choi and Lee's five-phase model[12] that was validated in a teacher education context, the case-based e-learning module for engineering design problem solving was developed. This e-learning module consists of four major phases: Exploring Situations, Constructing Reality, Creating Solutions, and Reflecting on the Process and the Product (see Figure 1). The purpose and learning activities of each phase are summarized in Table 1.

Figure1. Four Learning Phases

Table 1 Four Learning Phases for Engineering Design Problem Solving

1. Exploring Situations	Students are introduced to a real-world case problem and then build their initial ideas about problems and solutions. The goal of this stage is for them to realize the limitations of their thinking and to consider engineering design a process instead of a product.
(1-1) Exploring Situations	Students build their naïve understanding of situation and solution.
(1-2) Exploring Experts' Approaches	Students are exposed to multiple experts' approaches and reflect on their initial approaches while considering experts' approaches.
2. Constructing Reality	Students are exposed to the rich contexts of the problem situation and navigate necessary information to revise their understanding of the problem
(2-1) Articulating Questions	Students are asked to articulate what they want to know about the situation.
(2-2) Exploring Reality	Through the question-based interface, students seek information they would like to know.
(2-3) Exploring Interpretation	Students review/listen to how different experts interpret given situational information and reflect on their own thinking.
3. Creating Solutions	Students are exposed to multiple perspectives from different experts and build their own solutions.
(3-1) Articulating the Solution	Students are asked to propose their solutions and justify their own solutions.
(3-2) Exploring Experts' Solution	Students review/listen to different experts propose different solutions and their justifications for the proposed solutions.
(3-3) Refining the Solution	Students compare their solutions to experts' solutions and refine their own solutions.
4. Reflecting the Product and the Process	Students are asked to reflect on the process of problem solving and on the problem and solutions.

Purpose of the Study

Previous research indicated that second-year college students ranged between the late dualism and early contextual relativism stages during their college experience, and their positions influence their approaches to learn and to build expertise in solving real-world problems.[8, 12] Thus, the purpose of this study is to design and validate a case-based e-learning model that (1) promotes the epistemic development of the second-year engineering students from a dualistic level to a multiplicity level or above and (2) improves their abilities to deal with ill-defined, real-world problems.

Research Questions

1. Do the learning activities and the given learning resources in each phase of a given case-based e-learning module improve students' ability to deal with ill-defined, real-world problems?

2. Does the overall learning experience with a given case-based e-learning module improve students' ability to deal with ill-defined, real-world problems?

3. Does the overall learning experience with a given case-based e-learning module promote students' epistemic growth?

Methods

Participants and Procedures

A total of 34 Biological and Agricultural Engineering students who enrolled in a 16-week sophomore course entitled *Introduction to Environmental Engineering and Sustainability* in the spring of 2011 at a large southeastern land-grant university were the target participants in this study. Thirty-one out of 34 students submitted their informed consent forms to allow the use of their data for this study.

In this course, the instructor introduced different topics such as energy, water, natural resources, transportation, food production, materials use and processing, and waste handling. A 12-week implementation of this e-learning module was administered between the 2^{nd} week and the 15^{th} week of the course period.

After a brief orientation of the e-learning module, the epistemic beliefs survey (a 10-minute pretest) was administered in class. At the same time, a take-home, open-ended pretest for measuring students' problem-solving ability (*Case Problem: Water Supply for Atlanta and Metro-Atlanta*) was distributed to the participants. The completed pretests were collected during the next class, which was two days after the take-home pretest distribution. Over the following six weeks, the participants were encouraged to complete case-based online learning activities independently outside of class. However, many students did not complete the activities as planned, so an additional six weeks were given to them to complete the assignment. Once the participants finished all of the case-based learning activities, the same version of the in-class epistemic beliefs survey and take-home assignment were administered as a posttest. In addition, the participants completed the perceived learning experience survey. Upon the completion of the four-phase case activities in this study, the participating students earned up to ten points toward their final grade of the course. The instructor did not review the students' performance on the case activities during the semester.

Measurements

Epistemic beliefs inventory. The epistemic beliefs inventory developed by Schraw, Dunkle, and Bendixen[4] was used in this study. This inventory consists of 32 items and measures five sub-areas: simple knowledge, certain knowledge, omniscient authority, quick learning, and fixed ability.

Problem-solving rubric. The real-world problem-solving rubric developed by Choi and Lee[12] was adapted for this study. This rubric includes seven sub-skills for solving problems: (1) multiple perspectives in problem identification (PI), (2) justification in PI, (3) critical thinking in

PI, (4) linking to theory in PI, (5) solution and justification in solution generation (SG), (6) critical thinking in SG, and (7) linking to theory in SG. The adapted version of the rubric (0-4 score scales) was used to assess the quality of the student responses to the case-based online learning activities during the intervention and the case problem implemented as the pretest and the posttest. Two trained researchers rated the blind data independently and compared their validity. For the problem-solving tests, for example, these two raters agreed on 76.94% of their independent ratings and disagreed on 18.8% and 3.25% of their independent ratings by one point and two points respectively. Similarly, these two raters agreed on 77.78% of their independent ratings on the online case-based activities and disagreed on 13.78% and 1.2% of their ratings by one point and two points respectively. When there was a two-point gap between these two researchers' independent ratings, their consensus was reached through discussions. If there was only a one-point gap between the two ratings, we simply used their average score.

Results

Gain Test: Effects of Each Phase in the Case-Based E-Learning Module on Problem Solving

A one-way MANOVA with repeated measures was conducted to evaluate the effects of each phase in the case-based e-learning module on problem solving. To be free from the sphericity assumption, the multivariate criterion of Wilks's lambda (Λ) and the multivariate eta-squared (η^2) effect size were used.

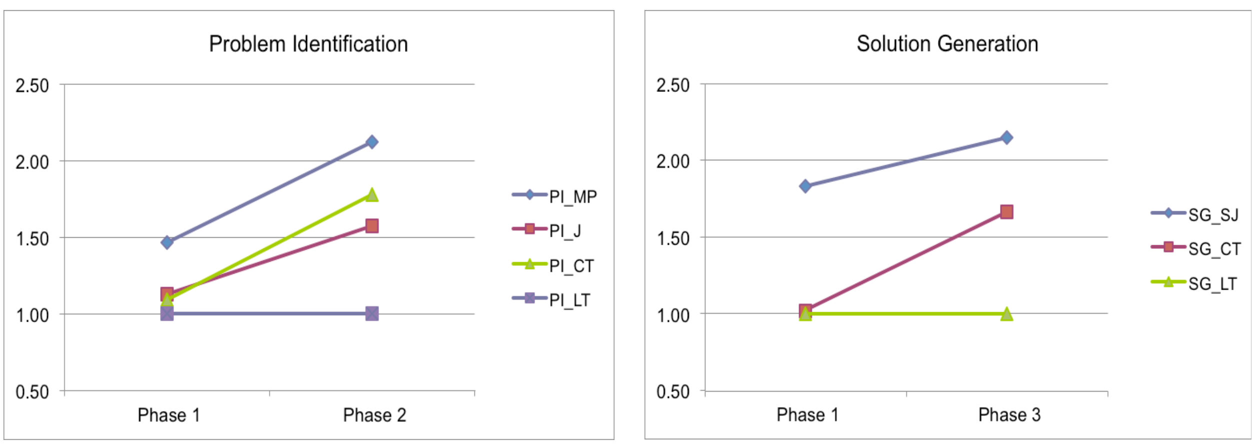

Figure 2. Guided Student Performance in Each Phase

Note. PI_MP: Multiple Perspective in Problem Identification; PI_J: Justification in Problem Identification; PI_CT: Critical Thinking In Problem Identification; PI_LT: Linking to Theory in Problem Identification; SG_SJ: Solution & Justification in Solution Generation; SG_LT: Linking to Theory in Solution Generation.

As depicted in Figure 2, the MANOVA results showed that there is a significant Time main effect [Λ = .23, $F(1, 23) = 78.67$, p = .000, η^2 = .78] meaning that students' problem-solving performances are significantly different among the different phases of the case-based e-learning module. A paired-sample t test for each sub-skill was conducted as a follow-up analysis. The results revealed that students' problem-solving performance were improved from the Phase One (the baseline) to the Phase Two in the following three sub-skills in defining problems: Multiple Perspective (Baseline, $M = 1.44$, $SD = .59$; Phase One, $M = 2.14$, $SD = .56$; $t\ (25) = 4.85$, $p = .000$, $d = .87$), Justification (Baseline, $M = 1.13$, $SD = .27$; Phase One, $M = 1.56$, $SD = .41$; $t\ (25) = 4.46$, $p = .000$, $d = .88$), and Critical Thinking (Baseline, $M = 1.08$, $SD = .18$; Phase One, $M = 1.81$, $SD = .58$; $t\ (25) = 6.17$, $p = .000$, $d = 1.21$). Likewise, students' problem-solving performances in proposing possible solutions were improved from the Phase One (the baseline) to the Phase Three in the following two sub-skills: Solution Justification (Baseline, $M = 1.82$, $SD = .33$; Phase Three, $M = 2.17$, $SD = .42$; $t\ (23) = 3.49$, $p = .002$, $d = .71$) and Critical Thinking (Baseline, $M = 1.02$, $SD = .10$; Phase Three, $M = 1.67$, $SD = .50$; $t\ (23) = 6.08$, $p = .000$, $d = 1.24$). There was no clear indication, however, that students are integrating what they read into their problem-solving process as the Linking to Theory scores in both identifying problems ($M = 1$, $SD = 0$) and generating solutions ($M = 1$, $SD = 0$) revealed no changes between the baseline and the later phases.

Transfer Test: Effects of Case-Based E-Learning Experience on Problem Solving

A one-way MANOVA with repeated measures was conducted to evaluate the effects of the students' learning experience with the given case-based e-learning module on their independent problem-solving abilities. The MANOVA results showed that there is no significant Time main effect [$\Lambda = .87$, $F(1, 23) = 3.36$, $p = .080$, $\eta^2 = .13$] but there is a significant Time and Sub-Skills interaction effect [$\Lambda = .26$, $F(5, 19) = 11.00$, $p = .000$, $\eta^2 = .74$]. The follow-up paired-sample t test analysis showed that the participants' Solution Justification skills in proposing possible solutions were significantly decreased from the pretest to the posttest (Pretest, $M = 1.76$, $SD = .34$; Posttest, $M = 1.12$, $SD = .43$; $t\ (23) = 5.17$, $p = .000$, $d = 1.06$). However, there were no significant differences between the pretest and the posttest in the remaining sub-skills.

Effects of Case-Based E-Learning Experience on Epistemic Growth

A one-way MANOVA with repeated measures was conducted to evaluate the effects of the students' learning experience with the given case-based e-learning module on their epistemic growth. The MANOVA results showed that there is no significant Time main effect [$\Lambda = 1.00$, $F(1, 19) = .04$, $p = .85$, $\eta^2 = .00$] and no significant Time and Sub-factors interaction effect [$\Lambda = .84$, $F(4, 16) = .76$, $p = .57$, $\eta^2 = .16$]. These results indicate that participants who experienced the given case-based e-learning module did not change their epistemic beliefs before and after their learning experiences with the case module.

Discussion and Conclusion

Problem-Solving Abilities: Guided Performance vs. Independent Performance

The results revealed that students' problem-solving performances were improved as they went through the four phases of learning activities in the case-based e-learning module. In particular, students' abilities to consider multiple stakeholders' perspectives, to justify their claims, and to critically examine given situations from broader socio-historical views were improved after they experienced how different experts interpret the given situation differently and how they frame problems differently during the Phase Two of the module. Likewise, students' abilities to propose solutions with justifications and to critically examine possible solutions from broader socio-historical views were improved after they reviewed diverse solutions proposed and justified by different experts during Phase Three of the module. These results are consistent with the results of Choi and Lee's previous study[12] with second-year teacher education students, meaning that Choi and Lee's adapted model is also effective on engineering students. Unlike Choi and Lee's study, however, the Linking to Theory skills in both identifying problems and in generating solutions are not improved in the current study. This could be explained by the amount of readings provided and the relevance of them to the given case problems. Choi and Lee's study[12] employed a few directly related readings to the problem, whereas the current study used much more reading resources with a broader scope. The participants in the current study might not review all the given reading resources and/or they might not be able to link between the problems and their readings and to integrate them into problem solving. To demonstrate how the students' approaches to dealing with the same problem have been changed through each stage of case activities, a sample of a student's responses and its scores rated by the raters were provided in Appendix A.

Unlike Choi and Lee's study,[12] the current study failed to show the transfer effects of the case module on students' problem-solving abilities. In Choi and Lee's study, they administered three small cases where students were guided to solve the given problem throughout the identical learning structure of five stages. One interesting result of their study was that students' initial responses to each case during their learning activities over three successive cases were not improved. In other words, after they showed the improvement of performance on problem solving at the end of the first case activity, they went back to their low performance in their initial responses to the second case while their problem-solving performance was improved again at the end of the second case activity. This pattern was repeated in each case activity. After three sessions of guided experience, the pretest and posttest comparison showed that the students were able to internalize certain skills to deal with ill-defined problems. Choi and Lee[12] found that the participants' guided performances (case activities) were consistently higher than their independent performance (transfer test). In contrast, the current study employed one large case where students went through the four learning phases only one time. This one-time case activity may be the major reason why the independent performance of the participants was not improved in this study. In conclusion, repeated learning experiences of solving ill-defined problems through different cases are necessary to internalize their independent problem-solving abilities.

As part of this research and development project, considerable amounts of time and resources have been invested in developing a case problem and related learning materials in order to represent the complexity of the problem case we developed and the great deal of content information that needs to be learned to deal with the problem case properly. Based on the results of the current study, however, we recommend that it is more effective and efficient to develop and implement smaller cases and related learning resources that can be finished within a short period of time (three to five hours of learning) if the primary goal of the learning module is to improve students' general approaches to deal with ill-defined problems beyond merely expanding the content knowledge. In this way, the students can explore the guiding structure of solving problems through each case activity repeatedly and thus they can internalize the general lessons learned from different cases, such as *the same situation can be interpreted differently* *from different perspectives*, *multiple stakeholders' perspectives should be considered to better understand the situation, multiple realities may exist simultaneously*, and *the claims should be justified with clear evidences and sound arguments*.

Epistemic Growth through the Case-Based Learning Experience

The current study found that there was no change in the participants' epistemic growth measured by the epistemic beliefs inventory[4] before and after the case intervention, which is consistent with the results of no-change in the transfer test on problem solving. We suspect that one session of case-based learning experiences may not be enough to influence the participants' changes in their epistemic beliefs. Therefore, this study recommends that a series of small case-based learning sessions that guide students' problem-solving abilities is necessary to help students to improve their problem-solving abilities and to advance their epistemic beliefs.

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Appendix A. Sample of Student's Performance Change During Case-Based Learning Experience

Problem Identification in Phase One -- Baseline

According to the given situation, Sarah and her family is going through a tough time financially. Her mom couldn't find work easily and the job that Sarah has at a restaurant could also be revoked or the hours might be reduced. Sarah also goes to college and needs to study for a better future of her own.

Average scores by two reviewers
(Multiple Perspectives: 1, Justification: 1, Critical Thinking: 1, Linking to Theory: 1)

Problem Identification in Phase Two

The issue that is being explained in this scenario is a very complex issue that is bounded by some social, economic, political, resource availability, and other issues. Thus when you consider the given case from all these different aspects, you can see how this problem is not just for one family but rather a structural problem that includes many other facades and thus an engineering and societal issue overall that needs to be changed or fixed.

Average scores by two reviewers
Multiple Perspectives: 2, Justification: 1, Critical Thinking: 2, Linking to Theory: 1

Solution Generation in Phase One – Baseline

The best thing that could happen is that Sarah's mom finds a job that pays a decent amount of money and that could help them financially. Another option could be if Sarah's two siblings find part-time jobs while in high school and help the family out.

Solution & Justification: 2, Critical Thinking: 1, Linking to Theory: 1

Solution Generation in Phase Three

In order to solve the societal issues that were presented within the context of the story of this family's issues, there needs to be a large-scale solution that needs to be implemented to solve the problems. A solution is needed for several different aspects such as the food production sectors issues presented in the previous videos. Now, in the food production sector several different problems were identified such as the transportation of food of several thousand miles, and farmers unable to sell their crops directly to retailers and others. Thus a solution such as allowing farmers to sell their crops directly to retailers without going through giant distributors would allow local fresh food easily available to other consumers.

Solution & Justification: 2.5, Critical Thinking: 2, Linking to Theory: 1