CREATING INTERACTIVE WEB-BASED ENVIRONMENTS TO SCAFFOLD CREATIVE REASONING AND MEANINGFUL LEARNING: FROM PHYSICS TO PRODUCTS

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ABSTRACT
With the evolution of the surrounding world market, engineers have to propose innovations in products and processes. Industrial innovation frequently results from an improved understanding of basic physics. In this paper, an approach to accelerate inventive preliminary design is presented. This method combines the main advantages of CBR (Case Based Reasoning) and TRIZ (Russian acronym for Theory of Solving Inventive Problem) to transfer physics to industrial technology. Based on this synergy, interactive web-based environments are developed. These systems are intended not only to enhance students to become familiar with basic physics, but also to support students in building meaningful links between basic physics and industrial technologies.

The evaluation was conducted in a "Special Project Design" course requiring students to design a robot that could carry out several functions. Robotics, an interdisciplinary engineering subject, has been a recurring theme in engineering education. Project-based learning provides opportunities for interdisciplinary learning. With project-based learning approaches, planning activities and investigations play a critical role in the project process. Through the web-based environments, students can explore the essence of basic physics, design technologies, and the integration of mechatronics. Further, web-based reasoning and meaningful learning modules are developed to scaffold creative design and to enhance student participation, motivation, and learning effectiveness. Quantitative and qualitative methods such as questionnaires and interviews were used to evaluate the effects of the developed system. Findings showed that inquiry modules were able to facilitate investigation and planning activities in product design stages. The responses obtained were very encouraging. Students in the course were appreciative of these on-going changes and indicated that these were indeed helping them to develop their engineering thinking and design skills, increasing their motivation to study.

INTRODUCTION
In every engineering field, engineers provide solutions, knowledge, and development, to improve and develop products. Consequently, all these trends and demands increase the need for innovation and anticipation of future trends in products and processes. In response, educators have developed a variety of pedagogical tools and curriculums to increase engineering student ability and competence. Robotics, being an interdisciplinary engineering subject, plays a key role in achieving this goal. Robotic design involves the application of a wide range of physics concepts. For example, to understand mechanism technology, students should have knowledge of mechanics. One of the more difficult aspects of teaching physics is helping students develop an appreciation for physics applications.

In the field of physics education, many studies developed a variety of methods to improve students' physics achievements. The consequences of the studies range from increased awareness and appreciation of good teaching and learning principles and practices, to strategic programs for increasing student interest and participation in physics (Tobias and Birrer, 1999; McDermott, 2001; Coletta *et al.*, 2008). Many research projects have concentrated on the factors effecting students' achievements in science and physics. Reasoning ability has been established as one of the important factors in science and physics achievement (Lawson, *et al.*, 2000). In recent years, studies in physics education have concentrated on students' conceptual understandings yielding important results in physics education. One of these results is that traditional teaching does not help or improve meaningful understanding in introductory mechanics. Employing instructional strategies involving inquiry methods have proven promising in helping students construct meaningful understanding (Lawson, 2007; Lawson, 1985; Lawson, 1992; Cavallo, 1996; Enveart, *et al.*, 1980; Cohen, *et al.*, 1978; Clement, 1993; Kahle and Damnjanovic, 1994; Thijs, and Bosch, 1998; Marshall and Dorward, 2000; Ates and Cataloglu, 2007, Liu, *et al.*, 2010). The inquiry-based learning (IBL) approach engages students in exploring meaningful questions through a process of investigation and collaboration (Thomas, 2003). In the IBL environment, students build their own knowledge through active learning, interacting with the environment as suggested by the constructivist approach, and working independently or collaborating in teams, while the teacher directs and guides and them in making a real product (Meng and Yang, 2003).

The emergence of the Internet has reformed the concept and methods of engineering education. Online learning, utilizing Web features, is increasingly important for education. In general, online learning environments have shown potential in promoting thinking skills (Saba, 2000; Isman, *et al.*, 2010). Furthermore, Dockrill (2003) found students through interactive teaching and learning facilitates acquisition of critical thinking skills. Despite the many benefits of e-learning, there is a risk of low motivation due to lack of face-to-face communication. In order to make the learning process effective, we need to motivate students in learning activities. Therefore, this study adopted a project-based learning (PBL) approach that is based on the creative problem-solving (CPS) model, to provide motivation, self-learning, and collaborative learning for students through the Web environment. The project-based learning approach engages students in exploring meaningful questions through a process of investigation and collaboration (Krajcik, *et al.*, 1999). In the PBL environment, students build their own knowledge through active learning, interacting with the environment as suggested by the constructivist approach, and working independently or collaborating in teams, while the teacher directs and guides and them in making a real product (Thomas, 2003).

DEVELOPMENT OF WEB-BASED ENVIRONMENTS FOR CREATIVE DESIGN

In this study, we propose a methodology to help students accelerate complex design and propose creative ideas. Generally, when we face a new problem, we use our early experiences and try to adapt them in order to produce a solution. This analogical reasoning is the most often used process during problem resolution. In artificial intelligence (AI), case-based reasoning (CBR) is one approach to manage knowledge. The main idea in CBR is that: similar problems have similar solutions. The CBR process uses and adapts earlier successful resolutions and solutions in order to solve new problems. This method is useful for repetitive design. For inventive design, its usefulness is more limited. In inventive design, problems are totally new and require solutions that are very distant from those already known. For this reason, CBR is coupled with the TRIZ theory (Russian acronym for Theory of Solving Inventive Problem). TRIZ is a problem solving method that increases the ability to solve creative problems. TRIZ is based on the analysis of knowledge used in technical domains. TRIZ has numerous advantages but some drawbacks. Each time one faces a new problem, to the process of resolution must be redeployed, which is time consuming. The proposed synergy eliminates this drawback by coupling TRIZ with CBR. CBR brings a way to model knowledge and accelerate the resolution. TRIZ offers the ability to eliminate barriers between technical domains and propose inventive solutions.

The model is presented in Figure 1. The central notion of the proposed model is a case. The initial step is to collect data that describes the handling problem and to fill the target problem features with specific values. After filling of the target problem features, the next step is to retrieve the case or a subset of cases, stored in the case base, that are relevant to solving the target problem. We need to adjust some features of the retrieved solution in order to answer the target problem; reused step. Next, the adapted solution is implemented, tested and repaired if necessary; the revised step. If the case base does not have any similar solved case or sufficiently similar case, the system offers inventive principles associated with general physics. One advantage of this model is its ability to learn with the incorporation of new cases in the case base; retain step. Failure like success can be stored in memory, because we also learn from failures. With this step, the system evolves, enlarging its coverage of problems and increasing its performance by extending the case base.

This system allows rapid resolution of problems through the use of past experiences in the domain of application but also in other domains through TRIZ. The transdisciplinarity between domains allows access to the best solutions, methods, and practices in all technical domains, leading to more inventive solutions. With this system, the students are not restricted to a domain, but are more open-minded.

This system is able to allow users to perform more activities online. The application tier side consists of a web server and a Java application server. A presentation tier consists of a client-side terminal that comprises the HTML, XML, and 3D web player plug-in. The client, which runs in a web browser, provides a student interface that handles input and output (displaying results and simulations). The web server performs actions and computations based on student input by using XML and JSP languages. The application server reads and writes to databases through a JavaBean. The content of the course is primarily presented with Web pages that are written in HTML. In order to move courses from one system to another, and extract and/or perform automated processing on documents, standardized definitions for course structures are necessary. To meet these requirements, Extensible Markup Language (XML) is used to develop course structures. In order obtain cross-platform application, the JAVA language is used in programming of the interactive Web pages.

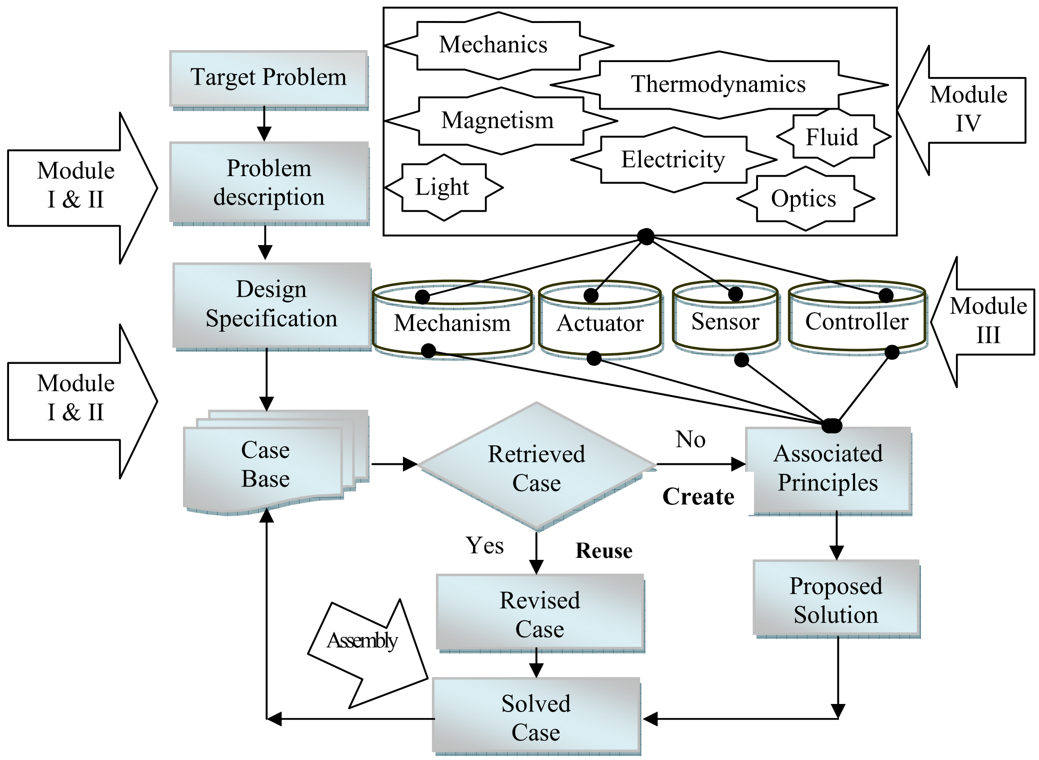

Figure 1. Elaborated framework for creative design

INSTRUCTIONAL MODEL AND METHODOLOGY

This research brings the creative problem-solving concept to develop the course model for basic physics and robotic education. The problem-based work of technology is characterized by the hierarchical knowledge structure of mechatronics, and the degree of teacher-centered planning. The problems, the guidelines, and the desired results, are provided in advance for the first type of PBL work. This type of PBL work is to intend to introduce students to relevant basic concepts of related disciplines of technologies involved in the design and fabrication of mechatronic systems. After students have gauged the interrelation between various related disciplines, they should able to explore their methods to solve the technological problems. Thus, the desired results will not be available to students in the second type of PBL work. They are only given guidelines for how to approach problems in the third type of PBL work. Students are confronted with the problems only in the last type of PBL work which is project-oriented. Students need to pursue solutions to open-ended problems by formulating questions for investigation, designing plans, collecting and analyzing information, and creating final products of their understanding.

The developed model is intended to not only enhance students to become familiar with the technical skills, but also to be able to use the skills to solve the problems given to them. The characteristics of this method give students more freedom to develop a question to investigate, devise an experimental procedure, and decide how to interpret the results. As a result, this teaching method focuses on students' skills in critical thinking and independent problem solving.

With project-based learning approaches, planning activities and investigations play a critical role. Students plan their work and create a synthesis of information retrieved from numerous resources. However, Meng and Yang (2003) pointed out that most existing search (Question and Answering) systems suffer from precision problems. Since the amount of available information is large, users waste considerable time in searching and browsing various websites to obtain the required information. Users must click and browse documents returned by keyword search to identify their desired information. When numerous documents are returned, users waste time dealing with many unsuitable documents. Studies of learner using the Web have indicated that students frequently fail to establish task-relevant, meaningful, reflective activity (Hill and Hannafin, 1997). The root problem is that keyword searches are not an ideal method for users to present their real intentions. To solve this problem, our previous studies developed two searching methods that process problem statements in natural Chinese language (Module I) and engineering drawings (Module II) to uncover the intention of the user query (Jou, *et al*., 2010). The developed semantic inquiry module interprets a student's question (i.e., document source) to extract the semantic information. The system then contrasts the source documents with the existing engineering database through heuristic rules to retrieve useful and precise results that meet user expectations. Besides the semantic inquiry module, another inquiry module, allowing students to describe their handling problem through engineering graphics. After uploading engineering drawings (2D or 3D), this module interprets the input data and extracts the engineering information from the case base to analyze designing methods. These two modules were integrated into the developed interactive web-based environment for students to investigate robotic manipulation including mechanisms, robot motion, and path planning. Students explored the website in advance and proposed what they wished to investigate through the developed inquiry modules by using natural Chinese language or graphs. The system responded to the questions with accurate answers in the form of contextual information. Students clicked desired items and browsed detailed documents that contained text, graphics, multimedia, and interactive simulations. Furthermore, students were able to observe robot arm link inertias of motions and study trajectory generation and control.

Figure 2 show the developed modules (Module III) for students to investigate robotic manipulation including mechanisms, robot motion, and path planning. Students explored the website in advance and proposed what they wished to investigate through the developed inquiry modules by using natural Chinese language or graphs. The system responded to the questions with accurate answers in the form of contextual information. Students clicked desired items and browsed detailed documents that contained text, graphics, multimedia, and interactive simulations. Furthermore, students were able to observe robot arm link inertias of motions and study trajectory generation and control.

Another function of this system is facilitating collective learning based on information obtained from associated principles of basic physics (Figure 3, Module IV). The design and development of this system allows for collection of data concerning students' design activities. This data is then analyzed by the system to promote designing activities. The system was developed to incorporate all the modules necessary to encourage creative designs. Furthermore, this system integrates asynchronous communication tools (discussion forums), a synchronous meeting tool that allows textual discussion and application sharing, and a tool for writing reports during the project.

Finally, this study provides a platform for students to assemble mechanical parts and integrate mechatronics (i.e. sensors, actuators, and control units) in designing robots. The assembly platform can allow students to design and modify mechanical components of robots to meet the project's expected goal. The platform of mechatronics was designed to help students in learning robotic sensors, actuators, and controllers. With this platform, students can design and construct functioning models, gaining experience and insight in designing robotic mechantronics. For robotic sensors, the learning content covers proprioceptive sensors, exteroceptive sensors, sensor performance, and design criteria. For actuators, the system contains a number of motors for study. Through this platform, students confront, and learn to deal with, the realities of robotic control.

Figure 2. Design and learning platform of robotics

Figure 3. Learning of basic physics and technologies for creative design

ASSESSMENT

The participants in this study were 30 sophomore students in a special project design course during the spring semester. The aim was to design a mobile robot that could perform a specific task. The participants were required to complete the course online without face-to-face instruction, working on their designs in small groups of 4-5 participants. They were encouraged to retrieve relevant information from the developed e-learning system. Following completion of the course, each group was required to submit a final technical report detailing the design process, the engineering considerations that led to the final design, a review of the relevant engineering literature, and the group's conclusions.

This study employed a pre-experimental approach without the utilization of control groups (Creswell, 1994).

Quantitative data were collected using questionnaires, while qualitative data were collected through interviews. According to Windschitl (1998), qualitative data can capture unique phenomena of online learning. The questionnaire also measured satisfaction toward the course, perceptions of delivery method, course structure, inquiry method, interactions among participants and with materials, and participant autonomy. The questionnaires were administered to the participants before and after completion of the online course. Follow-up interviews were carried out with the participants at the end of the course.

Table 1 shows perceptions of the various features in the interactive e-learning environments. Nearly 90 percent of the students agreed that the interface design was user friendly, simple, and attractive. In addition, they found the course content to be well organized. They also felt the inquiry modules facilitated investigation and planning activities in project development stages. Furthermore, these course activities were able to enhance interest in robotics. The students believed that the interactive e-learning environments not only helped them to enhance their problem solving skills, but also their technology integration ability. However, a small number of participants felt isolated while completing the online course. This can be attributed to the lack of face-to-face interaction. Interviews revealed students felt the course was challenging, stimulating, and fun. Students also showed a positive attitude toward robotics.

Student learning effectiveness was analyzed by employing laboratory exercises in robotics (Krotkov, 1996). After revising and correcting, there are 70 multiple choice questions in the test. The mean of passing and discrimination percentage are 0.57 and 0.33, respectively. Therefore, it could be called a reasonable test with a good passing and discrimination percentage. According to the result of the reliability analysis, the Cronbach's alpha value of internal consistency is 0.786. Moreover, criterion validity is based upon the significantly positive correlation of test scores for several universities. As a result, the test has good reliability and validity.

As shown in Table 2, the mean scores for mechanism design, manufacturing, application of actuators, and selection of sensors, before and after attending the special project course with interactive e-learning environments, were satisfactory. Integration of mechatronics, shows a mean score, before attending the course, of 7.47. This score indicates a moderate level of technical skill. After the course, a mean of 7.79 shows that the level of technical skills improved to satisfactory. Construction of control systems and assembly and testing scores were between 7.37-7.89, a moderate level. Significant improvements were observed in the technical skills of mechanism design ($t(36)=-2.39$ and $p=0.022$), manufacturing ($t(36)=-2.54$ and $p=0.015$), application of actuators ($t(36)=-2.40$ and $p=0.022$), and selection of sensors ($t(36)=-2.04$ and $p=0.048$). However, there were no statistically significant increases in technical skills for construction of control systems, integration of mechatronics and assembly and testing. However, data from the interviews indicated that most students showed higher interest and motivation toward problem solving in mechatronics and testing. Although students felt the projects were difficult and challenging, they were able to use appropriate technical skills to complete them. They were able to solve the technical problems at their own pace, collaborating among themselves.

Table 3 shows responses for two items associated with satisfaction with the interactive e-learning modules. Results showed that 93.3% of the participants agreed that the interactive e-learning modules had helped them to solve problems in project developing stages. (Mean, $M=4.2$; Standard deviation, $SD=0.551$). Furthermore, 90.0% of the participants believed that the interactive e-learning modules created a conducive learning environment ($M = 4.03$, $SD = 0.615$).

CONCLUSIONS

In this paper, we propose an interactive e-learning environment supporting creative design and design of robots at a distance. The developed inquiry modules allow students to present their problems in natural Chinese language fashion and through engineering graphics. In addition, this study developed interactive web-based environments to incorporate all the modules necessary for creative designs. This study examined the various important dimensions of web-based environments. Students generally provided positive feedback on the interactive learning environments employed in the special project course. Most students were satisfied with the inquiry modules, course activities, and interactions. In fact, they believed that these factors helped in their studies. Generally, interactive web-based environments can successfully enhance students' course achievements and technical skills.

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Table 1. Perceptions of the interactive e-learning environments

Items	Responses						
	SA	A	US	DA	SDA	M	SD
The online course enhances my interests toward learning.	8	20	2	0	0	4.20	.551
It is easy to gain access to technical supports.	5	22	2	1	0	4.03	.615
I can actively involve myself in the special project.	4	18	5	2	1	3.73	.907
The course materials satisfy my learning needs.	3	17	6	3	1	3.60	.932
The interface is user friendly and attractive.	10	17	3	0	0	4.23	.626
The online course contents are well structured.	7	18	4	1	0	4.03	.718
I can obtain the materials from the e-learning system for learning.	5	19	5	1	0	.393	.691
I can complete the project assigned within the time given.	20	9	1	0	0	4.63	.556
The group size is appropriate for robotic design project.	18	12	0	0	0	4.60	.498
The inquiry modules encourage learning through questions.	12	17	1	0	0	4.37	.556
I obtain feedbacks from inquiry modules as frequent as I need.	8	21	1	0	0	4.23	.504
I could interact with the inquiry modules as frequent as I need.	10	19	1	0	0	4.30	.535
I could obtain assistance to understand the content of the robotics from e-learning systems.	5	21	3	1	0	4.00	.643
I can understand the robotic course content from e-learning systems.	7	19	3	1	0	4.07	.691
The use of materials in the e-learning systems enhances my understanding of the robotics.	3	21	4	1	1	3.80	.805
I would like to repeat the experience.	18	11	1	0	0	4.57	.568

Table 2. Dependent t-test results: Students' ability of technical skills on robotics

		M[a]	SD	t	df	p-value
Mechanism design	Pre-test Post-test	7.748 .47	0.99 0.90	-2.39	36	0.022
Manufacturing	Pre-test Post-test	7.688 .47	1.00 0.90	-2.54	36	0.015
Application of actuators	Pre-test Post-test	7.168 .05	1.211. 07	-2.40	36	0.022
Selection of sensors	Pre-test Post-test	7.167 .89	1.210. 99	-2.04	36	0.048
Construction of control system	Pre-test Post-test	7.37 7.89	0.83 0.99	-1.77	36	0.085
Integration of mechatronics	Pre-test Post-test	7.47 7.79	0.90 1.08	-0.97	36	0.336
Assembly and Testing	Pre-test Post-test	7.47 7.79	0.901. 03	-1.00	36	0.323

[a]The maximum grade for each part of the question was 10.00, and the maximum grade for the entire question was 70.00.

Table 3. Satisfaction with the interactive e-learning environments

Items	Responses						
	SA	A	US	DA	SDA	M	SD
The interactive e-learning modules help me to solve problems on project developing stages.	8	*20*	2	0	0	4.20	.551
The interactive e-learning modules provide a conducive learning environment.	5	22	2	1	0	4.03	.615

Note: SA = Strongly Agree (5), A = Agree (4), US = Unsure (3), DA = Disagree (2), and SDA= Strongly Disagree (1), M = Mean, SD = Standard Deviation

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