Integrating constructivist elements into the design of a courseware for enhancing the learning of thermodynamics

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Abstract

A courseware for enhancing the learning of thermodynamics has been designed and developed based on ADDIE instructional design model with the integration of constructivism learning theory and visualization characteristics. The development of the courseware, which follows the guidance of the ADDIE model, has five phases consisting of analysis, design, develop, implement, and evaluate. The constructivist approaches incorporated in the courseware include attention, perception, comprehension, active learning, motivation, knowledge construction, and collaborative learning. Constructivist relevant learning elements that facilitate knowledge construction by learners applied were coaching, scaffolding, and modelling. Visualization is an important part of communications process, and graphical images can be used to add emphasis, direct attention, and illustrate concepts. The five characteristics of visualization applied were interactivity, practicality, interconnectivity, hierarchy and viscompana (visualize, compute and analyze). The visualization courseware combined a few methodologies for facilitating learning that are learning activities and simulations. In the design phase the topics chosen are structured in such a way to incorporate most of external events in order to maximize interest, learning, and retention so that they can be learned effectively. This include organizing content to make it clear, integrating techniques to enhance intrinsic motivation, and the incorporation of frequent and active learning participation as recommended in the constructivist learning environment. The design courseware was tested on March 2011. Results of the pre and post tests of the concept inventory test for energy and the first law of thermodynamics show a significant improvement in students' performance after learning using the courseware. The result is supported by paired sample t-test giving significant result in statistical analysis.

Keywords: Courseware, Visualization, Constructivism

1. Introduction

Amongst the challenges in engineering education today are the use of traditional methods of teaching, which has many disadvantages. Traditional lecture is also no longer suitable for educating the engineers in the age of advancement in computer technology. Although the usage of e-learning or computer technology is increasing in teaching and learning, it is still finding its foothold in engineering education due to poor ability to deliver effective learning products. This is due to the nature of many engineering courses that have difficult and abstract principles as well as many problem solving elements that make effective learning products difficult to design and develop. Poor instructional design result in little or no learning, misconceptions about course content, and also negative perceptions of using technology in learning (Tyler-Smith, 2006).

The development in learning theory, instructional design, e-learning, computer applications in education and learning styles can be used as guidelines to enhance the teaching and learning in engineering courses that many students have difficulties in understanding such as thermodynamics. The problems in learning thermodynamics involve difficulties in visualizing basic concepts and in problem solving are a global phenomenon (Mulop, Tasir and Mohd Yusof, 2011; Cotignola, Bordogna and Punte, 2002; Junglas, 2006; Anderson, Sharma and Taraban, 2002;

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Huang and Gramoll, 2004; Patron, 1997; Cox *et al*., 2003; Miller *et al*., 2009; Hall, Amelink and Conn, 2010; Loverude, Kautz and Heron, 2002). Thus, in engineering disciplines, students need additional support with illustrative animations, simulations, or further explanation with visualizations when they experience complex or abstract principles that are difficult to understand (Nguyen and Khoo, 2009). The visualization of any course can be in many forms, such as a multimedia courseware. Studies on the benefits of interactive multimedia systems reports that they give motivation, increase learning rate, contribute to retention, and effectively manage large classes of students with different learning styles (Atkins *et al*., 2003; Iskander, 2002; Kurtis, 2003). According to Teng *et al*. (2005) the main goal of using a courseware is to increase conceptual understanding of a specific subject apart from to gain calculation skills, to develop the ability to design a system or other desired needs, to gain high-level cognitive skills of reasoning, critical thinking and problem solving.

Given the difficulties that students face in learning thermodynamics (Mulop, Tasir and Mohd Yusof, 2011; Cotignola, Bordogna and Punte, 2002; Junglas, 2006; Anderson, Sharma and Taraban, 2002; Huang and Gramoll, 2004; Patron, 1997; Cox *et al*., 2003; Miller *et al*., 2009; Hall, Amelink and Conn, 2010; Loverude, Kautz and Heron, 2002), a courseware to assist students in learning and visualizing the first law of thermodynamics was developed based on constructivist approach and visualization characteristics using the ADDIE instructional design model. This paper describes the principles used behind the design of the courseware and how it was developed. A study on the effectiveness of the courseware as an aid for students to learn thermodynamics is also reported in this paper.

2. Development

The courseware is developed based on ADDIE instructional design model with the integration of constructivism learning theory and visualization characteristics. The ADDIE model has five phases consisting of analysis, design, development, implementation, and evaluation. The constructivist approaches incorporated in the courseware include attention, perception, comprehension, active learning, motivation, knowledge construction, and collaborative learning. Constructivist relevant learning elements that facilitate knowledge construction by learners applied were coaching, scaffolding, and modeling. Visualization is an important part of communications process, and graphical images can be used to add emphasis, direct attention, and illustrate concepts. The five characteristics of visualization applied were interactivity, practicality, interconnectivity, hierarchy and viscompana.

2.1 The ADDIE Model

The courseware was designed and developed following guidance from the ADDIE instructional design model because it is simple and also it is the basis of many other instructional design models. The ADDIE model has five step processes namely, analysis, design, development, implementation, and evaluation. The analysis phase involves analyzing the need for the development of the visualization courseware. After identifying the needs, an instructional analysis was conducted. The instructional analysis comprises of study on instructional goals and objectives; on students' characteristics such as students learning styles which are characteristic ways of taking and processing information; the students' current knowledge and skills; task analysis; as well as the learning environments. The Felder and Soloman's Index of Learning style (Felder and Soloman, 2004) was used for the learning style analysis. From the analysis it was found that 90% of the students are visual learners and 83% are active learners. Hence the visualization courseware developed caters for the majority of students. Development is the implementation of the courseware's design and includes the computer programming necessary to make the courseware functions. The courseware was developed using two softwares, Adobe Photoshop CS3 and Adobe Flash CS3 Professional. Each of the software used has specific functions in the development of the courseware.

Implementation as a stage in the ADDIE model can be of two types. The first refers primarily to the implementation activities that occur while the courseware is still being created, and is called pilot testing. The pilot test was carried out during semester 1, 2010/2011 session. The second refers to the launching of the courseware after development is complete, that is the process of installing the project in the real world context. The actual study was implemented on a section of students during semester 2, 2010/2011 session. The courseware was attached to the university's e-learning system for students to use. The purpose of this phase is the effective and efficient delivery of the courseware. Evaluation is the final stage in the ADDIE model. This phase measures the effectiveness and the efficiency of the courseware.

2.2 Constructivism approach

Constructivism approach is used as a basis for determining suitable learning strategies. Fundamentally, constructivism asserts that we learn through a continual process of constructing, interpreting, and modifying our own representations of reality based on our experiences with reality (Jonassen, 1994). According to Jonassen (1999), an important factor for reproductive learning is to engage learners in active, constructive, intentional, complex, authentic, cooperative and reflective learning activities. These activities are the goal of constructivist learning environments. According to Jonassen and Tessmer (1996/97), the recommended strategies are active learners need to engage in interaction with the environment that is constructed, as well as learners need to explore and strategically search through these environments. Intentional learners on the other hand, are willing to try to achieve the cognitive objectives; conversational learners may engage in dialogues with other learners as well as with the instructional system. Reflective learners articulate on what they have learned and reflect on the processes and decisions that were included in the process; and ampliative learners can generate assumptions, attributes and implications of what they have learned (Jonassen and Tessmer, 1996/97). The model used for designing the learning environment is based on Jonassen's model (1999). The model is shown in Figure 1.

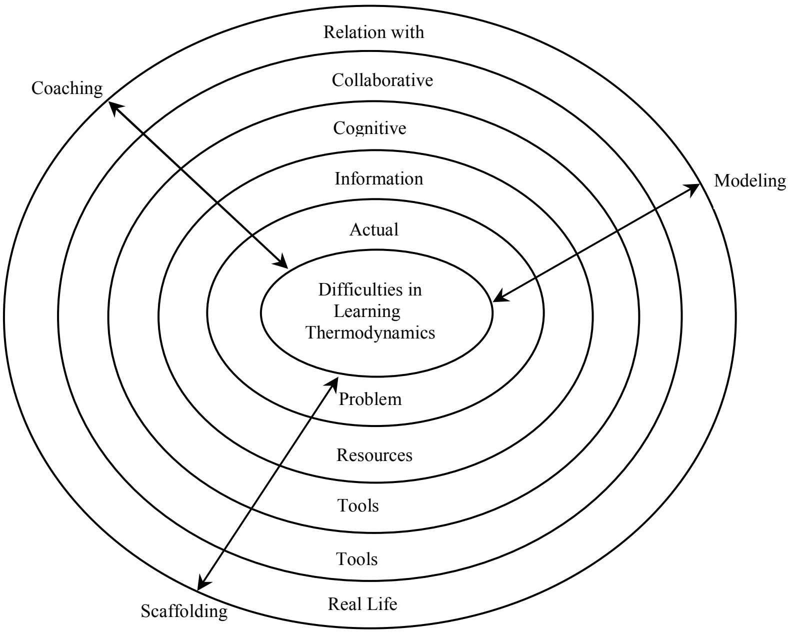

Figure 1. The model of learning environments used

Based on this model, the content used in the courseware is related to the problem of the study. Every content and learning activity is implemented in the constructivist learning environment with new information is interpreted in the context of the learner's own experiences, using cognitive and collaborative tools. The representation of the problem must be interesting, appealing, and engaging (Jonassen,1999). Cognitive tools are computer tools to be used for engaging and facilitating cognitive processing (Kommers, Jonassen and Mayers, 1992). They are used to visualize, organize, automate or supplant information. Cognitive tools support learners in a variety of cognitive processing tasks such as visualization that helps learners to construct those mental images and visualize activities (Jonassen, 1999).

The three instructional strategies based on constructivism are modeling, coaching and scaffolding are also used in the courseware to support the learners doing the activities (Jonassen, 1999). Modeling is the most commonly used instructional strategy in constructivist learning environment. Modeling provides learners with an example of the desired performance. A widely recognized method for modeling problem solving is worked examples. According to Jonassen (1999), coaching is a process of motivating learners, analyzing their performance as well as providing performance's feedback, and provoking reflection and articulation of what was learned. Thus, it helps regulate the learner's development of the required skills. On the other hand, scaffolding is a systematic approach to support the learner and is temporary (Jonassen,1999).

The Animations in the courseware represent coaching strategy that assists in developing comprehension. According to Jonassen (1999) students' understanding about something is enhanced through coaching strategy. The interaction design of allowing students to navigate forward and backward through the next and back buttons, to repeat the animation by clicking the replay button give students the flexibility of learning following their own paces and requirements. This characteristic gives students the freedom and control of their learning. According to Alessi and Trollip (2001), by giving students freedom and in control of their learning, can assist students develop understanding about a particular topic as well as motivate and increase their confidence. Constructivists have the opinion that by having control on the sequence of the course content, students have the opportunity to learn following their interest and requirements (Kennedy and McNaught, 1997).

The other interaction design is having a variety of questions in the courseware such as open ended (constructed response) question; tick the right answers with choice of answers in the form of animations, drag and drop answers question, roll over the answer and so on. According to Wager and Wager (1985), questions keep the learner attentive to the program, provide practice, encourage deeper processing, and access how well the learner remembers and understand information. Question is an interaction requiring thoughtful response should occur frequently (Alessi and Trollip, 2001). By responding to the questions allows students' interaction with the courseware and enhances students' thinking skill, thus enhancing comprehension and learning as well as building confidence. Answering open-ended questions encourage learner construction of information through discovery or guided discovery approach as stated in constructivist principles on learning process (Driscoll, 1994). Figure 2 shows an example of question in the courseware.

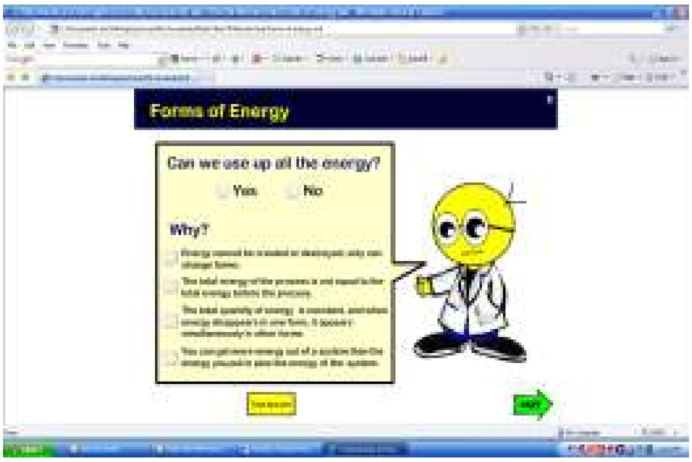

Figure 2. A screen capture showing a display of question

The courseware is also designed to give feedback on the responses on Questions given. The research literature concerning the role of feedback in learning is extensive and ongoing (Alessi and Trollip, 2001). The most common function of feedback is to inform learner about the correctness of a response. Feedback should encourage the learner to improve thinking and comprehension as well as can motivate the learner (Schimmel, 1988). The courseware provides test answer button for feedback on correct and wrong answers. If the answer is wrong, a try again button will appear and the learner can repeat answering the question. Getting the wrong answer can create conflict in student's mind. If the answer is correct, a display of 'congratulation, your answer is CORRECT' will appear. By praising the learner, it can motivate the learner and enhance his confidence level. Getting the right answer can function as a modeling element in constructivist learning environment. Apart from modeling strategy, feedback on answers given by students is a form of coaching strategy (Jonassen, 1999). Figure 3 shows an example of feedback on student's answer to a question.

Figure 3. An example of feedback on student's answer to a question

To help students identify the different processes in first law of thermodynamics, the courseware provides animation showing graphical diagrams of the processes. The graphs also function as a coaching element to help students identify the different processes (Jonassen, 1999). Figure 4 shows one of the processes with the graph.

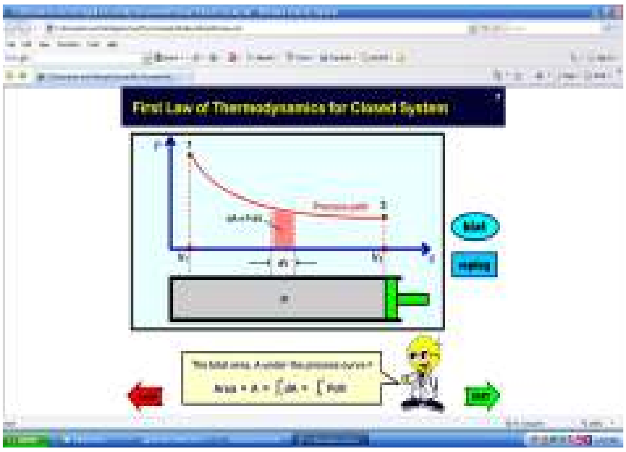

Figure 4. A graphical diagram to represent a process

By posting question in the e-learning forum it encourages students to give their reflection on the simulations in the courseware. According to Collins, Brown, and Newman (1989), effective learning strategies according to constructivism perspective and in many studies are modeling, scaffolding, coaching, discovery, articulation, and reflection. Reflection activity also functions as a coaching element (Jonassen, 1999). To assist students to give their reflections on their understanding about the simulation, the reflections given by their peers posted through the e-learning forum can be viewed by everyone. The presence of these reflections functions as a modeling strategy (Jonassen, 1999).

2.3 *Visualization characteristics*

In order to use visualization and simulation as an educational tool for enhancing learning and the quality of a courseware, certain elements and characteristics have to be considered in its design. According to Chaturvedi and Akan (2006), the common elements are the visualization of physical phenomena, the simulation of physical processes, and also the integration of virtual experiments. For the design and development of a courseware only the first two elemets are considered. Then, for maximizing the effectiveness of the visualization and simulation, five characteristics should be integrated into the courseware (Chaturvedi and Akan, 2006). The characteristics are interactivity, practicality, interconectivity, hierachy, and viscompana. These characteristics are related to knowledge, comprehension and exploration as stated in Bloom's Taxonomy of Educational Objectives (Bloom, 1986). The relation of the five visualization characteristics and the learning objectives in Bloom's Taxonomy (Chaturvedi and Akan, 2006) is given as follows:

i. Knowledge through Interactivity and Practicality,
ii. Comprehension through Interconnectivity,
iii. Exploration through Viscompana and Hierarchy

Relation (i) shows that knowledge is obtained through interactivity and practicality and is the basis of learning. Interactivity refers to students' ability to interact with the courseware. This characteristic assists in converting classrooms from an environment of passive knowledge transfer to an active student-centered learning environment. This is accomplished in the courseware in activities such as roll over, click, hints, and drop and drag buttons as well as answering questions or problem solving. They can visualize a number of simulations of everyday life engineering phenomena in the courseware by the clicking action of the mouse. Interactivity is also part of constructivist learning environment as students interpret and construct meaning based on their experiences and interactions with the courseware. The activities of using the various buttons promote exploration, experimentation, construction, and reflection of what the students are studying (Jonassen, 1999). The hints buttons give reminders to students of the relevant underlying principles. To strengthen understanding the students are engaged in 'learning by doing' exercises and thus offering them the opportunity to practice and test their skills.

Practicality relates to the content of the courseware which emphasizes on real world aspects of engineering principles and their governing equations (Chaturvedi and Akan, 2006). The presence of various examples of visual images and simulations of energy applications in everyday life give students the practicality aspects of thermodynamics. The virtual interactive exercises in the courseware can assist students to relate engineering phenomena and processes to their operating parameters. From the figure of the learning pyramid, comprehension is achieved through interconnectivity. Interconnectivity refers to the capability of the courseware in building students' knowledge and experience obtained in previous courses or subject materials and projecting that to future learning (Chaturvedi and Akan, 2006). For example, students are expected to give other examples apart from that shown in the courseware, and to calculate problems applying the principles given. The visualization courseware has been developed to give awareness to students that the topics of energy, its applications, and the first law of thermodynamics are interconnected. In constructivist learning environment, interactivity is also achieved through learning in a collaborative manner with peers. This is carried out by the use of e-learning forum which enables students to ask questions and for other members of the class to respond and share their understanding and knowledge on related topics. Learners share information to collaboratively construct socially shared knowledge (Jonassen, 1999).

Students' exploration to attain knowledge is achieved through hierarchy and viscompana as shown by Figure 5. Hierarchy refers to the capability of the courseware in guiding students from elementary knowledge and principles to more advanced learning through pre-arranged sub-topics with succeeding sub-topics providing a higher level of learning compared to the previous one (Chaturvedi and Akan, 2006). For instance, in the courseware, the first level of hierarchy is the basic principles of energy. The second level of hierarchy provides students with simulations and animations on the application of the first law of thermodynamics. The hierarchical arrangement of the contents gives students the flexibility of setting their own learning goals and their pace to achieve them. The hierarchy characteristics of the courseware enable students to explore so as enhancing learning about related topics and aspects that is not covered in conventional lecture.

Viscompana is a combination of three short forms of words, vis for visualize, comp for compute and ana for analyze (Chaturvedi and Akan, 2006). The courseware shows graphics and simulation for students to visualize together with solving problems and exercises to allow them to compute and analyze the solutions. In addition, each answer input by the students stimulates feedback. Feedback is intended to provide information that encourages the revision and refinement of students' thinking (Dollar and Steif, 2006).

3. Results and Discussions

The topics covered in the courseware were energy and the first law of thermodynamics. The courseware consisted of five simulations. The effectiveness of the courseware was determined by using pretest and posttest which was administered using a thermodynamics concept test that was validated by two experienced lecturers who had taught thermodynamics. Both the pretest and posttest were given to the students without any announcement of the tests in order to reduce threats to internal validity. Figure 5 shows the number of scores in the pretest and posttest for all respondents. The result shows that there is a significant increase in the score of posttest for every student.

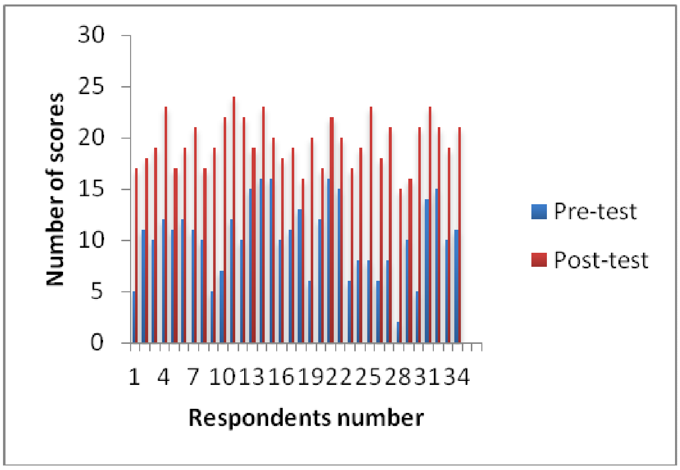

Figure 5. The distribution of pre-test and post-test scores for the respondents

The percentage distributions of the means of the pre- and post- tests are shown in Table 1. From Table 1, it shows that the mean score of the post-test is higher than that of the pre-test. The pre-test was given after 4 -8 weeks the topics have been covered in normal class. There is an increase in performance of 90.94% after using the courseware for 25 days. If 50% (equivalent to 14 score) is taken as the passing score, the mean of the pre-test shows that the respondents failed the test. However, in the post-test all respondents obtained more than the 50% of passing score.

The paired-sample t-test analysis of mean of the pre-test and post-test of respondents is shown in Table 2. From Table 2, the p-value of 0.0% means that the statistical analysis gave significant result on learning using the courseware. This indicates that differences of mean scores between before and after using the courseware are significant.

Table 1. The percentage distribution of the result of pre-test and post-test

	Pre-test	**Post-test**
N	34	34
Mean of total correct answers	10.26	19.59
% of total score	36.7	70.0
Std deviation	3.63	2.36

*Total score = 28

Table 2. The paired-sample t-test analysis of mean of the pre-test and post-test

Test	**N**	**Mean**	**Std. deviation**	**P**
Pre	34	10.26	3.63	0.000
Post	34	19.59	2.36	

4. Conclusion

From the result obtained, the developed visualization courseware integrated with constructivist elements and visualization characteristics has enhanced the performance of diploma in Mechanical Engineering students at Universiti Teknologi Malaysia in learning thermodynamics. The students were no longer passive elements in the process but became active players capable of interacting with and constructing their own learning. Thus, the courseware can be used to supplement and complement class instruction.

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