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# Learning and Teaching Engineering Courses with Visualizations

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**Abstract— Engineering students learning about engineering analysis and design usually experience such complex or abstract aspects that they may not be able to fully understand without additional tutorial lessons or further explanations with visualizations. As examples, when learning construction technology students need to visualize materials and sequences of construction process, i.e. how all components of a facility are assembled? Such visualization can not be achieved in a textbook and a traditional lecturing environment. This paper presents the development and implementation of a computer tutoring software, in which a new method of teaching, named 'learning with visualizations' is designed to assist students in deeply understanding and effectively mastering materials. The tutoring software was used to teach a construction engineering management course at California State University, Long Beach. The evaluation of the effectiveness of the tutoring tool is also discussed.**

*Index Terms*—**Learning Effectiveness; Learning Assessment; Teaching Methods; Visualization; Engineering Education.**

## I. Introduction

In engineering disciplines, students learning about engineering analysis and design typically experience such complex or abstract aspects that they usually need additional tutorials with illustrative animations, simulations, or further explanations with visualizations. As examples, (i) when learning construction technology, students need to visualize materials and sequences of construction process, i.e., how all components of a facility are assembled; (ii) through animations/visualizations, electrical engineering students can visually observe the performance of different types of modulators and demodulators; thus enabling them to deeply understand the characteristics of the communication components; (iii) in chemical engineering, intuitive understanding may be developed when students observe visual interactions among numerous atoms, and subject those simulated atoms to fundamental laws of nature such as conservation of energy, gravitational and electrostatic forces, conservation of momentum, etc.; and (iv) in computer science, interactive visualization has become a recognized branch of knowledge that studies how human-computer interaction create graphic illustrations of information efficiently. In short, each discipline in engineering and computer-related field lends itself to incorporating interactive simulations in teaching and learning.

Indeed, visual simulations or visualizations cannot be achieved using just a textbook and a traditional lecturing environment. The need to integrate advanced education technology tools such as interactive simulations and visualizations into the curriculum. It has been recognized by accrediting bodies that these tools enhance student learning and improve quality of engineering education (Atkins, et al., 2003; Bouchlaghem & Beacham, 2000; Messner & Horman, 2003). In effect, studies on the benefits of technology-based education demonstrate that interactive multimedia units provide motivation, increase learning rate, contribute to retention, and even help effectively manage large classes while supporting the teacher as facilitator (Atkins, et al., 2003; Iskander, 2002; Kurtis, 2003). This paper presents the development and implementation of a computer tutoring software, in which a new method of teaching, named 'learning with visualizations' is designed to assist students in deeply understanding and effectively mastering materials. More specifically, the visualization-based features of the proposed tutoring framework help increase classroom interaction and students' personalized learning experience. Sample problems and assignments can be integrated into the framework so students can directly participate in class discussion and exercises as well as study these concepts more thoroughly at their own pace independently. The tutoring software was used to teach construction engineering management courses at California State University, Long Beach. The evaluation of the effectiveness of the tutoring tool will also be discussed.

## II. Background

In investigating effective and engaging ways to teach engineering courses, a literature review of pertinent research and best practice reveals principles that support the use of visualization and offer ways to optimize their use through co-constructed meaning and application. These principles will be used as guidelines for developing the proposed visualization-based learning and teaching framework. Findings are summarized as follows.

*Use of Visual Simulations*: When teachers incorporate visual simulations of real-life scenarios into their classroom activities, students participate more and have a more satisfying learning experience (Duran, et al., 2007). Visual simulations are particularly effective at deepening understanding of abstract and highly mathematical subjects such as electromagnetics (Iskander, 2002). Likewise, 3D animation and walkthrough computer models demonstrate

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construction processes, and complementary text describes the various steps for dual coding of information (Haque & Saherwala, 2004). Additionally, studies have shown that today's students are more attuned to computer and video technologies and are likely to learn better if they are provided with computer-based modules (Kurtis, 2003).

*Different Visual Tools*: At different stages in the students' learning, different types of visual tools should be considered. For example, at the instructional stage, simulations can be more structured in order to check for understanding throughout the module. When students progress to the analysis and application stage, they welcome more unstructured environments where they can script their own engineering experiments, and control their own learning (Uran & Jezernik, 2008).

*Gaming Elements*: In education, gaming displays several characteristics that foster deep learning: active and manipulative environment, authentic complex and contextualized content and tasks, ability to reach a goal using a variety of routes and strategies, peer interaction, combination of cooperation and competition, increased sense of control and investment of effort (DeKanter, 2005).

*Core Learning*: Because engineering is often couched in terms of its applications, developing curriculum with core concepts across engineering disciplines can be difficult. Nevertheless, when students work with faculty and community experts to learn core engineering concepts through visual simulation games, test those concepts in the real world, and then apply their academic and field experience to develop their own engineering games, they can learn deeply and contextually (Boardman & Clegg, 2001).

## III. The Proposed Visualization-Based Tutoring Framework

In the proposed tutoring framework (refer to Figure 1), the content of materials to be covered will be organized in three main sections: *Learn*, *Practice*, and *Assess*. These three separate sections enable students to achieve deeper understanding as they undergo a three-stage learning process: (i) *Learning:* first, students will go through the dialogues and visualizations to enhance their knowledge and understanding. Links between relevant documents are provided within the materials allowing students to review themselves the materials of interest, thus resulting in better memory of what was learned, (ii) *Practicing:* second, students are prompted to solve practical problems using their acquired knowledge, and apply what was learned to unfamiliar problems, and (iii) *Assessing:* finally, their learning will be assessed by means of questions as "food for thoughts". Their answers to these questions will be scored and the scores will be used to assess their resulting learning against objectives of the course. For each chapter, based on the assessment outcomes (i.e. the student scores), the tool will provide the student with recommendations for what topics in the chapter need to be reviewed before going further in subsequent chapters.

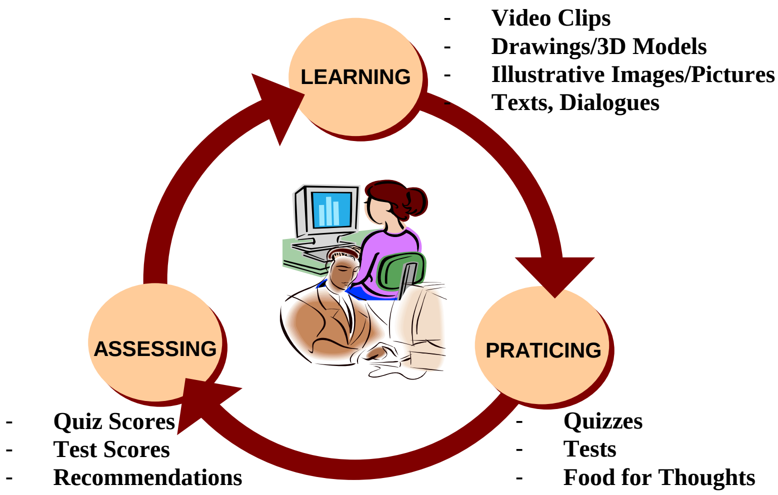


**Figure 1**. *The Proposed Tutoring Framework*

## IV. Implementation and Results

The proposed tutoring framework described above was implemented into a computer platform through three steps. First, the learning materials were prepared and organized in chapters, sections, and subsections including texts, dialogues, and illustrative visualizations (e.g. video clips, drawings, 3D models, images, and photos). At the end of each chapter, questions as 'food for thoughts' were given as multiple-choice quizzes or tests, which will be scored to assess the student's knowledge. Second, the user interface for the proposed tutoring tool was designed such that the student will be able to interact with the learning tool through illustrative visualizations and dialogues rather than just reading or watching. Basically, having learned a subject, the student will be prompted to answer questions about the subject to test if the student has completely understood the material. If the test score turns out to be low, the student is recommended to go over again the learning subject before moving onto the subsequent ones. Finally, the proposed tutoring framework and the user interface were implemented into a computer platform to obtain a visualization-based tutoring tool, named VisuaLearning. Macromedia Studio 8 is adopted for the implementation of VisuaLearning since it offers the broadest range of creative tools to create interactive dialogues and visualizations using advanced graphics, text, animation, video and audio tools. VisuaLearning was used to teach several classes at the Department of Civil Engineering and Construction Engineering Management at California State University, Long Beach (CSULB) including CEM 304 (Applied Mechanics – Strength of Materials) and CEM 121 (Construction Drawings). Below is an example input and output of VisuaLearning for the CEM 121 class.

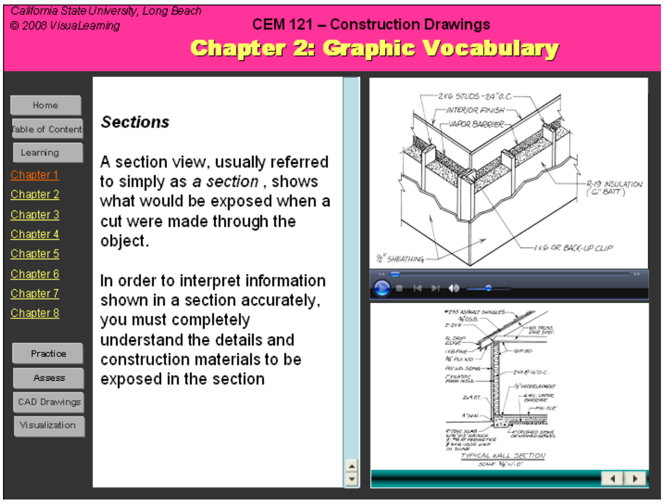


**Figure 2**. *Typical Wall Section*

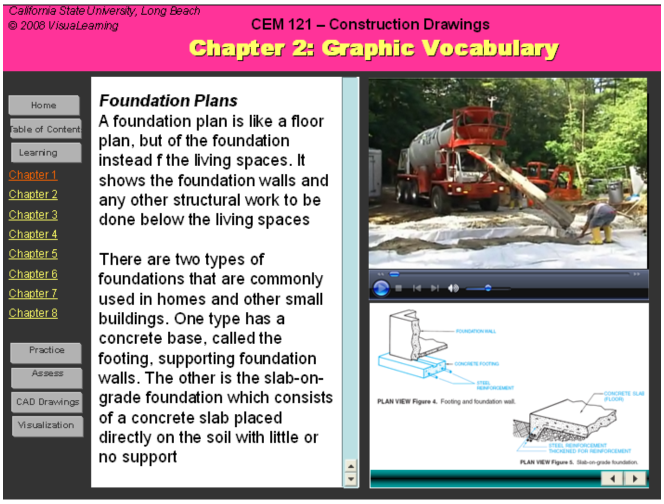


**Figure 3**. *Concrete Foundations*

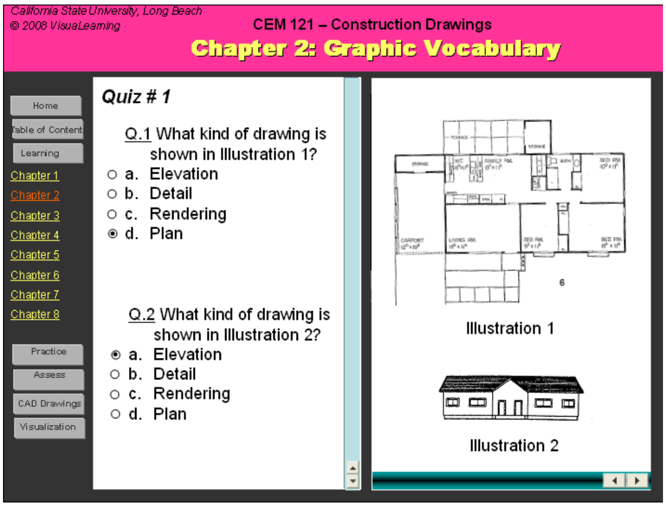


**Figure 4**. *Quiz # 1*

Before VisuaLearning is ready for students to use, the instructor needs to edit learning materials for the course of interest. Figures 2 and 3 show the typical screen shots of the VisuaLearning in which texts, 3D images, video clips, and drawings were entered as illustrative visualizations for typical sections and foundations of a residential construction project to be covered in the course CEM 121 (Construction Drawings).

After going over the learning materials for a particular subject (e.g. Graphic Vocabulary), students are prompted to answer questions in a quiz or test about what have been learned. These quizzes and tests are scored to make sure students understand the materials before going further in the subsequent chapters. Figure 4 is an example of the quiz for Chapter 2: Graphic Vocabulary taught in CEM 121.

The quiz scores and assessment results are reported to provide students with recommendations on what materials should be reviewed for deeper understanding. Figure 5 shows a typical assessment report.

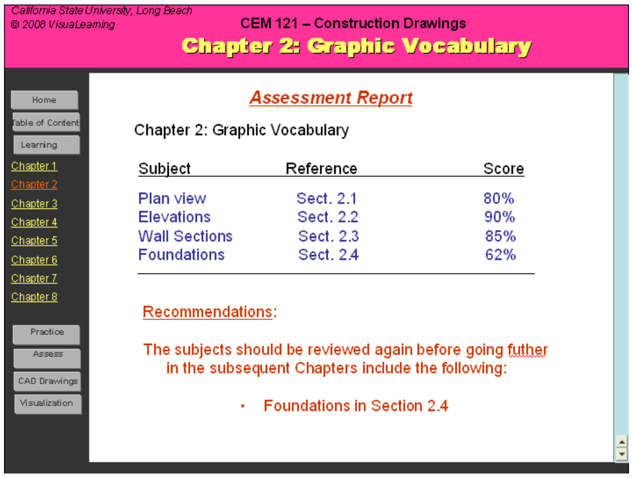


**Figure 5.** *Assessment Report*

## V. Assessment of the Effectiveness

The assessment of an engineering course with respect to student expectations or learning objectives is a necessary activity for enhancing the course quality. The assessment tools such as homework, quizzes, tests, exams, lab reports, oral presentations, and projects were used as evidences of the overall student achievements with respect to the learning objectives of the course where the proposed visualization-based tutoring framework was implemented. In addition to the student works used as the assessment tools, a survey questionnaire was developed and used to assess the effectiveness of the tutoring framework.

Survey Questionnaire: At the end of the semester, students were asked to provide feedback on their experience with the proposed tutoring framework by completing a questionnaire. The questionnaire (refer to Figure 6) consists of two parts: rating response and narrative response. In the rating response portion, students were asked to rate their experience on various features of the framework using the five-level scale (Strongly disagree-Disagree-Neither-Agree-Strongly agree). Student's responses to each question were converted into a numeric value between 1 (Strongly disagree) and 5 (Strongly agree) for data analysis. Based on the data collected from all students in each class (or subject), two-way ANOVA was used to test the statistic significance of the responses. At the end of the questionnaire, students were asked to provide narrative responses. Their comments will be incorporated into developing the next generation of the tutoring framework.

Project: A Visualization-Based Tutoring Framework

SURVEY QUESTIONNAIRE

**For the following questions, please choose the response that best describe you**

**Gender**: o Male o Female

**Race**: o American Indian o Asian o Black or African American o Hispanic or Latino o Native Hawaiian or Pacific Islander o White

**Age**: o below 17 o 17-21 o 22-26 o 27-30 o 31 and above

**Are you the first generation engineer/scientist in your family?** o Yes o No

**Current GPA**: o below 2.0 o 2.00-2.99 o 3.0-4.0

**The concepts are explained clearly**.

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**The interactive video/simulation is useful to understanding the materials**.

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**The pace in which you learn is appropriate**.

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**The assessment and feedback provided is effective in identifying your area of improvement.**

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**The framework helps you learn the material**.

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**The framework provided you with real application examples similar to your work.**

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**The framework covered materials that you can apply directly at work.**

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**The framework helped prepare you to the workforce.**

o Strongly disagree o Disagree o Neither o Agree o Strongly agree

**Figure 6.** *Student Survey Questionnaire*

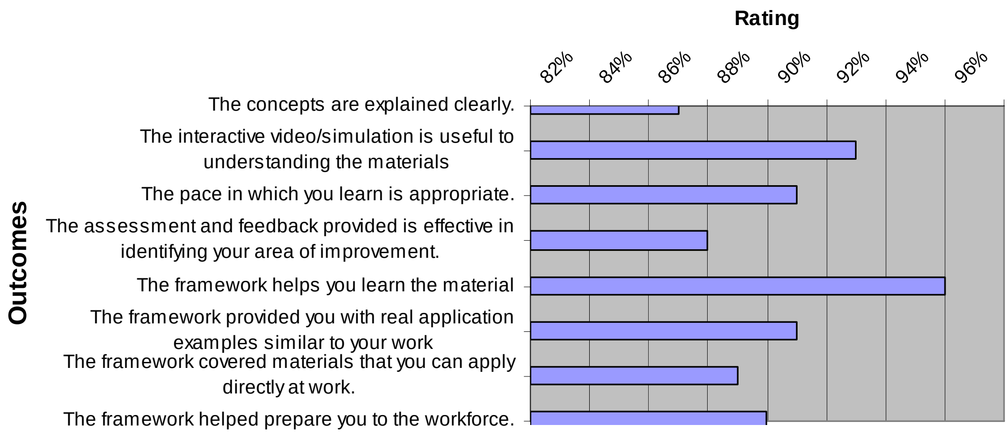


**Figure 7**. *The Survey Result*

The questionnaire includes questions related to the student's educational and demographic background which will enable us to evaluate the effectiveness of the proposed framework by different categories.

Survey Results: The proposed tutoring framework that was used to teach construction engineering management courses was assessed for its effectiveness by means of the survey questionnaire described above. Figure 7 shows a typical result of the survey on the effectiveness of the tutoring tool used to teach in class CEM 121 – Construction Drawings. The survey result indicates that the framework overall helped students to learn materials as the outcome was rated as 96%. However, the instructor should make sure that the concept explanation is clear and understandable since the rating for this outcome is as low as 87%.

Discussion: Because the instructor developed the learning objects, he/she can control the content, aligning it with the desired course and program outcomes. The instructor is able to incorporate learning objects in class as a way to engage students and bridge class time work with outside or distance course learning. The learning objects also facilitate consistent learning experiences between course sections. The instructor can also use the feedback information to determine effective targeted interventions (e.g., instruction, resources, support) to address specific learning gaps; these analyses and actions will be shared with other instructors to optimize teaching efforts. It should be noted that close instructor-student interaction in the typically large classes of introductory courses can be problematic. The visualization-based features of the proposed interface helped to increase classroom interaction and students' personalized learning experience. Sample problems and assignments can be integrated into the framework so students can directly participate in class discussion and exercises. Overall, the framework helped promote students' understanding and interest in engineering, which can lead to higher student retention rate.

## VI. Conclusion

According to recent research projects on education, the use of interactive visualizations help students deeply understand abstract and highly abstract engineering subjects in engineering courses. A computer tutoring framework was developed and implemented into a number of engineering courses at California State University, Long Beach. The proposed tutoring framework was incorporated with visualization learning objects including graphics, animation, video, and illustrative images/photos, which are found to be very effective in learning and teaching engineering courses. These learning objects consist of modules that will help students achieve deeper understanding (learn), apply learning to unfamiliar problems (practice), and optimize achievement of predefined learning outcomes through a diagnostic feedback loop (assess). Learning objects were designed to address basic, intermediate and advanced knowledge to provide spiraled learning. The visualizations provide dynamic representations of knowledge and improve accessibility of instructional materials because the learning objects provide an alternative to text. The interactive approach enables students with different learning styles to comprehend theoretical constructs and apply them in grounded practice. The constructivist paradigm is further enhanced with the technology's built-in diagnostic feedback loop, which optimizes individualized learning. The proposed tutoring tool was also evaluated for its effectiveness in learning and teaching of engineering courses. It was reported that the tutoring tool overall helped students to effectively learn materials.

## Acknowledgement

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