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Effects of 3D-Simulation-Based Instruction on Students' Achievement and Interests in a Manufacturing Engineering Class*

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The purpose of the study was to compare and analyze the effects of two instructional methods—instructor-led and simulation-based instructions—on engineering students' achievements and course interests in a manufacturing engineering class. Twenty-nine undergraduate students participated in the study, and repeated measures were employed to collect multiple sets of data. The study showed no significant differences in the means of achievement and interests. The results are discussed in conjunction with the data tables.

Keywords: manufacturing; 3D simulation; course interest

INTRODUCTION

MANY ENGINEERING EDUCATORS integrate on- and off-campus field trips and hands-on laboratories into engineering curricula to compensate for the limitations of 2D visual aids, which have been prevalently used as the major learning materials. 2D visual aids tend to lack the dynamics and concreteness of manufacturing processes, thus triggering the need for outside-the-classroom learning environments and means. However, there are difficulties associated with outside-the-classroom learning (for instance, field trips), such as: (1) coordinating the schedules of the students, owing to the differences in their class schedules as well as the availability of manufacturing sites; (2) the provision of transport; and (3) the lack of provision of hands-on experiences on-site for the students, due to large group sizes (typically 15 to 20 students per group).

Manufacturing engineering is a rapidly developing discipline that requires a comprehensive understanding of how products are designed, manufactured, distributed and operated. It is extremely important for industrial and manufacturing engineers to be able to visualize the processes from the component level to the systems level, as this leads to optimized decision making in terms of material and process selection.

3D simulation, which is a computer-generated representation of a phenomenon in three spatial dimensions, is considered one of most effective methods in solving current engineering problems that involve complex configurations. 2D and 3D simulations, including interactive, Web-based delivery modes, have been implemented with varying degrees of success in a range of disciplines, including solid mechanics [1], fluid mechanics [2], robotics [3], materials science [4], chemical process automation [5], and semiconductor devices [6]. 3D-simulation-based instruction is expected to maximize students' understanding of manufacturing processes by: (1) helping them visualize the

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dynamic processes in 3D (as compared with still-life, 2D visuals); (2) capturing the essence of manufacturing processes in a simplified and realistic manner (as compared with real-life movies, where many captured components can serve as distractions); and (3) bridging the gap between conventional classroom instruction and real situations. Ultimately, 3D-simulation-based instruction is expected to produce technically competent manufacturing engineering graduates with the ability to understand fundamental physical phenomena and the governing principles of manufacturing processes, and to design, analyze, and optimize processes and systems. Through simulation, it is proven that the students can apply their sufficient knowledge and skills pertinent to the subject of their study [7, 8].

The purpose of the study was to examine the impact of 3D simulation on engineering students' achievements and course interests in a manufacturing engineering class. Specifically, this study compared two instructional methods: (1) traditional instructor-led instruction, in which an instructor delivered a direct lecture using a white board, supplemented by limited 2D visuals, such as hand-sketched drawings, photos, and printouts; and (2) 3D-simulation-based instruction, in which the instructor incorporated computer-generated 3D simulations into the lecture. The data based on a series of surveys and grades were analyzed to assess the effectiveness of 3D-simulation-based instruction.

Subject

Undergraduate students (n = 29) registered in a junior-/senior-level course EIN 4312 Tool and Process Engineering offered by the Department of Industrial and Manufacturing Engineering (IME) at the Florida A&M University–Florida State University (FAMU-FSU) College of Engineering participated in the study. The participants' ages ranged from 18 to 22. They participated voluntarily and were assured of the confidentiality of their responses to the study.

Course description

EIN 4312 is a required course in the Department and is offered as a follow-up course for EIN 3390C Manufacturing Processes and Materials Engineering. The course serves as a core part of the curriculum that aims at preparing the students for tackling materials, design and manufacturing problems in the field. The course was selected because it could be a representative course in which simulation-based visuals significantly enhance students' perception of how manufacturing processes are performed, what process parameters are involved, and how the processes can be optimized. In particular, EIN 4312 focuses on such topics as tool design, workholding, jigs and fixtures, and process planning in an economic framework.

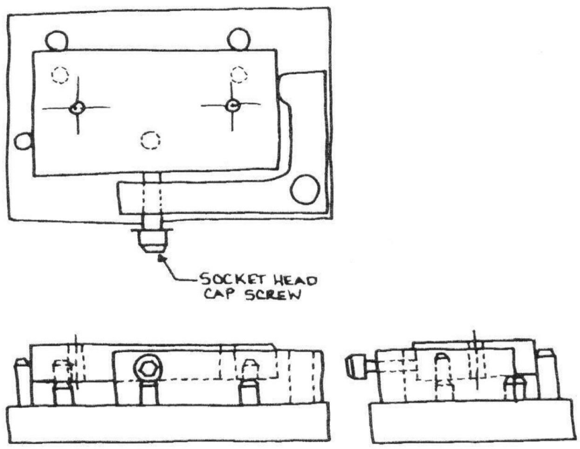

Fig. 1. Hand-sketched drawing of a simple jig system extracted from the textbook [9], showing three orthogonal 2D views.

Instructional material

Commercial 3D graphics software was used to develop 3D models and a manufacturing process simulation case showing a fixture system from design to assembly. In order to compare the effectiveness of simulation-based instruction, 2D instructional material was used as the "control" instructional medium (Fig. 1).

Figure 1 shows three views (front, top, and right side) of a simple drilling jig system provided by the textbook currently used in class [9]. (A "jig" is a type of workholder designed to hold, locate and support a workpiece while guiding the cutting tool throughout its cutting cycle.) The jig system consists of three main subsystems: (1) the workpiece, depicted as a rectangular bar with two through-holes; (2) the locating components consisting of six round pins supported by a base plate; and (3) the clamping components, including an L-shaped clamp and a screw. It is not intuitive from Fig. 1 what types of components are involved, how the components are assembled, how the locating principle works, and how the components interact with one another.

The 2D still images can be replaced by 3D animation to enhance students' perception by helping them visualize the dynamics of the moving parts. Figure 2 shows an example of a simple 3D animation, illustrating a step-by-step procedure of jig system assembly. (Four representative frames are captured and shown.) In Step (a), the workpiece to be fixed onto the jig is shown. The workpiece makes a rotation about the vertical axis to provide a 360° view. While rotating, the workpiece turns semi-transparent to show the inside features (in this case, the two holes). Upon completion of rotation, the workpiece returns to its original configuration, recovering its color and texture. In Step (b), the six locating pins "fly in" from various directions to lock the position and orientation of the workpiece, followed by the support plate as shown in Step (c). Finally, in Step (d), the L-shaped clamp "flies in" from the top and assembles

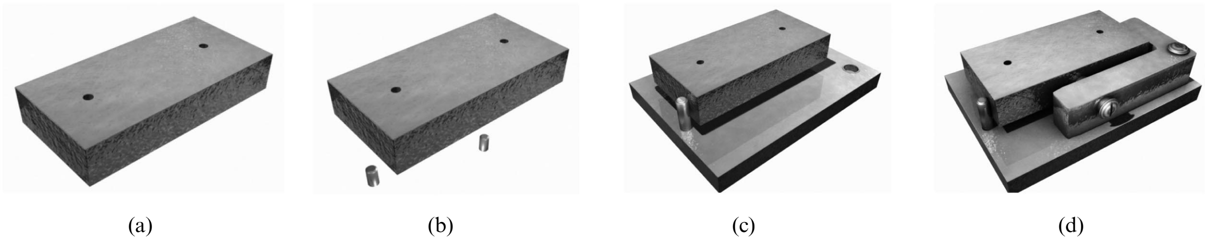

Fig. 2. Snapshot images captured from the 3D animation of jig system assembly: (a) workpiece; (b) assembly of locating pins according to the 3-2-1 locating principle; (c) assembly of jig plate; (d) assembly of L-shaped clamp.

into the jig system. The clamp is pivoted at the corner, and its capability to rotate about the pivot is animated to show its range of motion. The screw that is used to adjust the angle of the clamp, thus the clamping force, "flies in" from the front to secure the clamp and complete the jig system.

The components of the jig system were rendered to respective colors and textures depending on the type of material. (In this case, rolled steel for the workpiece and jig plate, and extruded stainless steel rods for locating pins.) The example animation incorporated: (1) translational and rotational motions of the components; (2) step-by-step assembly process; (3) semi-transparent coloration, whenever applicable; and (4) 360° views at various stages. These features provided the students with a realistic feel for how the assembly is actually performed and how the components interact with one another. The developed animation was in AVI format, and was played using an LCD projector installed in the classroom.

Instrument

We measured the students' achievement using two conventional test formats (mid-term exam and final exam), which required them to solve multiple choice questions, short answer questions, and open-ended questions. The final scores for each test were calculated by a rubric to judge the correctness of each answer. The total score of each test was 100. We also measured the participants' reaction to course interests in terms of 34 items specified in the "Course Interest Survey (CIS)" [10]. The CIS consists of four sub-scales: Attention, Relevance, Confidence and Satisfaction. The participants responded to five-choice Likert-scale items for sub-scales with answer options ranging from "Not True (1)" to "Very True (5)." The average score for each subscale and the total scale were reported. The survey was administered prior to each exam.

Procedures

The study took place during regularly scheduled class periods throughout one semester (Spring 2005). The class was held Mondays and Wednesdays, and each class period was 1 hour and 15 minutes long. At the beginning of the semester, we distributed the informed consent forms to the subjects to grant voluntary inclusion of their responses in the study. The semester was divided into two sessions, and the participants took part in both sessions. In Session 1 (January 5–February 28), the instructor taught the course primarily based on printed text material (instructor-led instruction). The visuals were restricted to sketches, schematic figures and printed photos in the textbook. The instructor collected the participants' first achievement score from mid-term exam and the course interests data. In Session 2 (March 2–April 20), the instructor used the developed simulations, animations and movies as the primary instructional tool (3-simulation-based instruction). Although the instructor used the lecture as a primary means to convey the course material, the 2D-dominated visuals were replaced by the 3D visualization and simulation cases. The instructor collected the participants' second achievement data from the final exam and course interests.

Data analysis

We adopted Repeated Measure Design, the purpose of which was to measure the performance data of the same participants more than once to analyze the influence of the 3D simulation cases on students' performance. In the analysis, the achievement scores and course interests of the two instructional modes were treated as dependent variables. The achievement score and course interests data were analyzed by paired t-test for the mean scores on the tests. Comparisons of the means of achievement and course interests were accomplished by pairwise comparison test. We used the commercial statistics software SPSSTM as the analysis tool.

RESULTS

Preliminary analysis

Descriptive statistics for the mean and standard score of each dependent variable across each instructional mode is presented in Table 1. The resulting sample size was 29. An initial screening of the data did not show any outliers; therefore, all of the data were retained. Kolmogorov–Smirnov's test of the normality setting with the alpha level at 0.05 for the dependent variables— (1) achievements for instructor-led instruction ($z = 0.095$, $p > 0.05$) and simulation-based instruction ($z = 0.119$, $p > 0.05$) and (2) course interests for instructor-led instruction ($z = 0.100$, $p > 0.05$) and simulation-based instruction ($z = 0.117$, $p > 0.05$)—indicated

Table 1. Descriptive statistics for the dependent variables

	Instructional mode			
	Instructor-led instruction		Simulation-based instruction	
Dependent variables	M	SD	M	SD
Achievement (n = 29)	87.31	8.54	86.59	7.74
Course Interests (n = 29)	3.53	0.48	3.63	0.40

Table 2. Paired t-test for the achievement test

	M	SD	t	df	Sig.
Achievement 1—Achievement 2	0.724	8.62	0.452	28	0.655

Note: Achievement 1: Achievement of instructor-led instruction.
Achievement 2: Achievement of simulation-based instruction.

Table 3. Paired t-test for the course interest test

	M	SD	t	df	Sig.
Course interest 1—Course interest 2	–0.097	0.75	0.689	28	0.497

Note: Course interest 1: Course interest of instructor-led instruction.
Course interest 2: Course interest of simulation-based instruction.

that the scores of the dependent variables were normally distributed.

Achievement test

The paired t test (t[28] = 0.452 , $p > 0.05$) in Table 2 indicates that the difference between the two means of achievement was not statistically significant (See Table 2). Therefore, we can conclude that 3D-simulation-based instruction did not enhance the achievement of the students significantly.

Course interest survey

The paired t test (t[28] = 0.689 , $p > 0.05$) in Table 3 indicates that the difference between the two levels of course interest was not statistically significant (See Table 3). Therefore, we can conclude that the effects of 3D-simulation-based instruction on the increase in course interests were not significant as compared to the instructor-led instruction.

Sub-scales of course interest survey

Tables 4 and 5 show that the 3D simulation did not play a major role as an instructionally effective strategy. The attention scale, which measures the level of students' attention and interest in the course material, did not change significantly (t[28] = 1.792, $p > 0.05$). The relevance scale, which measures the effectiveness of the instructional mode to help students understand the relevance of the learning objective, also did not show strong evidence that the 3D simulation matches the needs, value, and expectations of students (t[28] = 0.306, $p > 0.05$) [11, 12]. In addition, the confidence scale, which measures the capability of the

Table 4. Descriptive statistics for sub-scales of course interest

	Instructional mode			
	Instructor-led instruction		Simulation-based instruction	
Dependent variables	M	SD	M	SD
Attention (n = 29)	3.004	0.677	3.341	0.552
Relevance (n = 29)	3.804	0.631	3.858	0.521
Confidence (n = 29)	4.086	0.519	4.017	0.550
Satisfaction (n = 29)	3.234	0.492	3.299	0.472

Table 5. Paired t-test for the sub-scales of course interest test

	M	SD	t	df	Sig.
Attention 1—Attention 2	–0.336	1.010	1.792	28	0.084
Relevance 1—Relevance 2	–0.054	0.945	0.306	28	0.762
Confidence 1—Confidence 2	0.069	0.824	0.451	28	0.656
Satisfaction 1—Satisfaction 2	–0.065	0.750	0.467	28	0.644

Note: Attention, Relevance, Confidence, and Satisfaction 1: Sub-scales of instructor-led instruction; Attention, Relevance, Confidence, and Satisfaction 2: Sub-scales of simulation-based instruction

teaching method to instill confidence in the students to accomplish the course successfully, decreased. The 3D simulation seemed to be more challenging to the students and led them to attribute learning success to his or her own effort and ability ($t[28] = 0.451$, $p > 0.05$). Finally, the satisfaction scale, which measures the degree of students' enjoyment of learning processes, did not show significant improvement ($t[28] = 0.467$, $p > 0.05$).

DISCUSSION

Despite the educational advantages of simulation and simulation-based instruction, the students in this study did not show any significant improvement in achievement over those who had had instructor-led instruction. This can be explained by the experiential interaction and performance test. The simulation was originally developed to provide students with interactions in situations where the students meet complex real problems. However, the simulation implemented in the study did not fully support the experiential interaction, which enables students to manipulate components and objects of simulation. In other words, the instructor simply adopted a format of delivering a lecture, using 3D simulation cases [13, 14].

Another possible reason that the 3D simulation was not effective is that the achievement test was not appropriate in measuring the learning outcomes or mental processes of the students when they dealt with the simulation cases. Therefore, evaluation of learning and performance in simulation should be varied in terms of hands-on modeling tests, protocol analysis of simulation manipulation, simulation portfolio evaluation, or real world case studies.

The result indicated that the 3D simulation did not show significant impact on students' course interest. As indicated above, 3D simulation may increase the novelty effects, which refers to the phenomenon that an attentive newness of a program dramatically decreases as time passes. However, the novelty of the 3D simulation have not sustained for a significant duration. That is, the students considered the 3D simulation cases as interesting software at the beginning, but the components inherited in the 3D simulation failed to maintain the attention of the students [7].

The following modifications in terms of instructional system design are suggested:

- *Incorporate 3D-simulation-based instruction into EIN 3390C (Manufacturing Processes and Materials Engineering), which is a prerequisite course for EIN 4312.* The same instructor teaches both courses in two consecutive semesters. In the present study, the students who took EIN 4312 were already taught by the same instructor in the previous semester in EIN 3390C, and therefore, their responses to the surveys may have been biased by the preconceptions they had about the instructor. In addition, EIN 3390C is a more appropriate course for incorporating 3D-simulation-based instruction, as it focuses on complex manufacturing processes, where visualization and parametric studies are more meaningful. A better way to decouple student bias from EIN 3390C to EIN 4312 would be to choose two EIN 3390C classes (offered in two different academic years) as the study cases—one based on traditional instruction and the other based on 3D simulation.
- *Involve more intensive 3D simulations in EIN 3390C throughout the semester*. The simulations used in EIN 4312 were rather limited in terms of their quantity and length. The students showed interest, but they definitely wanted to see more. Using 3D simulations for a portion (say, half) of the course was not effective because it did not give the students sufficient time to adapt to the new instruction mode. In order to allow the students to absorb the messages and lessons delivered through simulations, they should be exposed to the new instructional method consistently throughout the semester.
- *Upgrade simulations so as to involve interactions with students and incur their participation.* As opposed to the "movies" used in this study, where only the "proper" procedures for the assembly of mechanical systems were demonstrated (and the students were mere observers), interactive simulations will allow the students to change parameters virtually, build their own systems, and observe the results of their decisions. In addition, the modified and improved simulations will be supplemented by narration and sound effects to maximize students' understanding and to stimulate their interests.

In summary, the results reported in this paper suggest points of improvement in terms of instructional design, implementation, and assessment methods. According to the discussions with students, 3D-simulation-based instruction increased their course interests and helped them visualize, and they definitely wanted to see more of it. For 3D-simulation-based instruction to be truly effective in enhancing students' learning, it needs to be interactive. The simulations should provide the students with a visual means to mimic a real-life industrial working environment, to incorporate their rationale-based decision-making, and to display results reflecting their decisions.

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