ASSESSEMENT OF 4D MODELING FOR SCHEDULE VISUALIZATION IN CONSTRUCTION ENGINEERING EDUCATION

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ABSTRACT: This paper describes a longitudinal study to assess the value of using 4D modeling in construction engineering education for schedule visualization. In 2005, a preliminary 4D learning module was developed and incorporated in a project management course to help students learn how to develop a Short Interval Production Schedule. Comparative assessment methods were used to examine the learning product (solution quality). Direct observation and surveys were used to examine presentation effectiveness and student perceptions. This assessment concluded that 4D modeling is an effective learning aid for students to better achieve learning outcomes. In 2006, a more rigorous assessment methodology was designed to determine the impact of the 4D learning module on both the learning process and final exercise product. In addition to examining a traditional 4D modeling process, we also developed a 4D model generation interface titled the Virtual Construction Simulator (VCS), which allows students to generate a construction schedule directly from a 3D model. Ten student groups using these two interfaces were observed, videotaped, analyzed and compared. The final results from a detailed content analysis of the videotapes shows that both processes were valuable for improving the students' learning experience. The VCS interface showed additional value beyond the current 4D CAD application.

KEYWORDS: 4D modeling, engineering education, schedule visualization, game engine.

1 INTRODUCTION

When a student in design and engineering disciplines is learning to develop a construction schedule for a building, the student will typically develop the schedule by interpreting 2D drawings, identifying activities from the 2D drawings, and building a network schedule from these activities. Developing a construction schedule is difficult since a person must construct the building step-by-step in their mind after interpreting the 2D drawings. The paper investigates the value of using 4D modeling applications which allow for the visual representation of the construction schedule time with the 3D model components. The 4D model can provide a common visual language for students when learning how to develop construction schedules for buildings.

4D modeling is becoming more prevalent in the construction industry. Benefits of 4D CAD technology used in the Architecture, Engineering and Construction (AEC) Industry have been studied and documented in recent years. 4D modeling allows project teams to visualize construction plans; identify construction consequences and space conflicts; identify safety issues; and improve communication of the project team members (Koo and Fischer 2000). While there are an increasing number of successful applications of 4D modeling in the AEC industry, its implementation in engineering education remains limited. To address this limitation, a longitudinal study was conducted, which focused on the implementation of this valuable tool in construction engineering education and the quantitative assessment establishing its effectiveness.

2 THE LEARNING MODULE

A learning activity was used to investigate the value of the 4D modeling applications. This learning activity was developed from a construction project, the MGM Grand Hotel Renovation in Las Vegas, Nevada (see Figure 1). The hotel has a cross shape with a tall core and four symmetric wings. It has 30 floors, where the first four floors are cast-in-place reinforced concrete, and the other 26 floors are precast concrete structure. The structure had a very tight schedule and needed to be finished within 9 months to meet the owner's objectives.

Since the precast concrete structure is repetitive for each floor, this project was used in a senior level project management course (AE 473) to teach students how to perform the Short Interval Production Scheduling (SIPS) method. The assignment requires students to develop a SIPS for constructing the precast concrete structural system for a typical floor of the hotel within the time, crew, and equipment constraints. In previous implementations of this assignment, students were given a 2D plan (See Figure 2) of a typical floor, along with pictures taken from the construction site so that they could visualize the structural system and develop a SIPS.

3 THE PRELIMINARY 4D LEARNING MODULE

In 2005, a 4D learning module was developed using a commercial 4D modeling application. An overview of this learning module and the assessment results are provided in the following sections.

3.1 *Development and incorporation of the preliminary learning module*

A 3D model of a typical floor of the hotel (Figure 3a) was developed using a 3D CAD application. A schedule template (Figure 3b) was created using MS Project scheduling software. Student groups developed their SIPS in the schedule template, and then linked their schedule with the given 3D model using the NavisWorks with TimeLiner 4D modeling application (NavisWorks, 2006). The 4D CAD application allowed students to review and test their solutions. Final solutions were exported into video files for submission. Student groups also presented their solutions to their classmates and the instructor (Figure 4) on a 3-screen display in the Immersive Construction (ICon) Lab.

3.2 *Evaluation of the preliminary learning module*

The value of the 4D learning module was evaluated by examining the final schedule quality, observing student group presentation and conducting a survey (Wang et. al. 2006).

3.2.1 Group product

The learning product (solution quality) was assessed by using a scoring rubric to compare the 2005 results to the student performance in 2004, when students developed the schedule using only the 2D drawing and pictures. In the schedules developed by the students using the 4D learning module, we found students better utilized the construction space by having more overlapped activities, considered more issues related to work flow and resources, and have more logic sequence since the 4D model helped them identify sequence conflicts. Though we observed a higher quality in the schedules developed using the 4D learning module, the average grade in year 2005 (86.75) was lower than that in 2004 (89.41). One reason was that it was much easier for the teaching assistant to identify mistakes from a 4D model than from a CPM schedule, which made the grades lower than the previous year.

3.2.2 Presentations

Student presentations and discussions were observed when student groups presented their solutions on a large 3-screen display in the ICon Lab. In previous years, the instructor reviewed all the solutions from student groups, and then discussed the most common problems with students in class. With the help of the 4D model, each student group explained their SIPS to other students and the instructor in class. Since the 4D CAD model graphically presented the SIPS, students could review the SIPS developed by other groups and experience multiple outcomes for the same learning exercise. Each group could also get immediate feedback on their solution. The 4D CAD model made the learning activity more interactive by allowing students to review and critique different solutions.

3.2.3 Student perceptions

A survey was conducted after the presentations and discussions regarding students' perception of this 4D learning module. Survey results showed that students felt the learning module helped them in understanding SIPS, reviewing schedule solutions, understanding alternative solutions, and improving group communications (Figure 5).

4 THE REVISED LEARNING MODULE

The preliminary learning module was evaluated by examining the quality of the final activity "product", presentation effectiveness and student perceptions towards the 4D learning module. This assessment concluded that 4D modeling is an effective learning aid for students to better achieve the learning outcomes within the SIPS activity. Based on this study, a second study was designed which focused on a more rigorous assessment of the impact of using 4D modeling to improve the learning process. The preliminary learning module was improved and parameters for assessing group process effectiveness were developed. In addition to examining a traditional commercial 4D modeling process, we also developed and assessed a more interactive learning application by using a schedule generation interface developed in a game engine, which allowed students to generate a construction schedule directly from a 3D model.

4.1 *Learning module improvements using the commercial 4D modeling application*

In 2005, students made several general mistakes in their schedule that may have been caused by not being able to visualize the overall construction environment. In 2006, the 3D model of the project was improved to provide students a more realistic environment and more accurate detailed model (Figure 6a). The schedule template (Figure 6b) was the same as the previous year. Student groups developed their SIPS in the NavisWorks with Timeliner 4D modeling application using this improved module.

4.2 *Development of the learning module using the VCS interface*

At the same time, the researcher also developed a Virtual Construction Simulator (VCS) by using a 3D game engine interface (Deep Creator). 3D game engines have been successfully used to visualize building construction projects, simulate building environments, and perform interactive walkthroughs (Miliano 1999; Shiratuddin et al. 2004). A 3D game engine allows a user to learn more about a construction process by interacting with the building elements. Different from the current 4D CAD process, which generates a 4D model by linking a 3D model and an existing construction schedule, the VCS allows direct generation of a construction schedule and a 4D model from a 3D model. The VCS was designed to allow a group of students to interact with the 3D model, group 3D building elements into construction assemblies, create activities from within the 3D interface, sequence activities, and generate a 4D model and a CPM schedule. Following the development of the 4D schedule, the activities and their sequence can be reviewed and revised. Figure 7 shows the user interface of the VCS.

4.3 *Incorporation of the improved 4D learning module and the VCS learning module*

In 2006, the 4D learning module in the two different interfaces were incorporated into AE 473 at Penn State for the SIPS project. An experiment was conducted where five student groups (control group) used the commercial 4D learning module and five groups (experimental group) used the game engine interface. Each group was video recorded and the quality of their final solution was evaluated. The research hypothesis was that the added interactivity of the 3D game engine interface would provide a better learning environment for the students.

The experiment was conducted by using the 3-screen display system along with a SMART Board interactive whiteboard as a fourth display in the ICon Lab. The three screens were used to display the 3D / 4D model of the project, and the SMART Board allowed users to control computer applications directly from the display. In this experiment, the SMART Board was configured to allow a user to interact with either a MS Project schedule (the control group) or a SQL database (the VCS group).

The control group used the MS Project displayed on the SMART Board to develop their SIPS schedule. Then the schedule was loaded into NavisWorks with Timeliner, which included the 3D model of the project. The students linked their schedule activities to the appropriate objects in the 3D model in NavisWorks. When complete, the group would review their schedule by using the 4D model. They were able to revise their original schedule on the SMART Board and update the schedule so that they could see the revisions in the 4D model. Figure 8 shows a control group developing their schedule in the ICon Lab.

The experimental group used the VCS learning module to select 3D objects in the model and group them. They were also able to create activities and sequence them from within the 3D model. Group inputs were saved to a SQL database and displayed on the SMART Board, which allowed the group to review the activities and the sequence they generated. Figure 9 shows students in an experimental student group discussing sequencing alternatives when they were developing their initial schedule. They developed the schedule and the 4D model at the same time after they went through this process. Then they were able to visualize the 4D model and make revisions.

Each student group presented their 4D model to the class and the instructor in the ICon Lab after their final submission. The instructor and the class asked questions, provided comments and discussed alternatives regarding each specific 4D model. Figure 10 is a picture of one group presenting their 4D model to the class.

4.4 *Assessement of the VCS learning module*

4.4.1 Group process

In educational research, parameters typically used to measure a group process include open communication, supportiveness, conflict, and individual input (Gladstein 1984). One focus of this research was on measuring the group communications and interactions to evaluate the group process effectiveness. This was achieved by performing a content analysis for each video recorded from student group meetings. A video analysis application (Studicode) was used to obtain the time for each category of communication that was predefined by a multi-level coding scheme. Figure 11 shows the coding scheme used in this research.

4.4.1.1 Communications

Group communications were broadly divided into project related communications, technical communications and other communications. Project related communications had five sub-categories: goal clarification, solution generation, analysis, evaluation and decision. These categories were adopted from Badke-Schaub (2002). Badke-Schaub developed a generic model based on basic cognitive operations to analyze team communication in the design process when solving a design problem. Within the learning activity, the students are solving a process design problem. These communication categories were defined as follows for this research:

1. Project related communications
   - Goal Clarification: Questions, answers, or statements, which clarify the goals and objectives which the group needs to achieve along with the requirements which they need to fulfill.
   - Solution Generation: Questions or statements, which propose potential solutions or new ideas which were not proposed previously within the group's discussion. Some solutions could be more detailed solutions of the previous ones. These solutions can be related to meeting any of the goals within the project, including activity duration, division of work, resource utilization, or activity sequencing.
   - Analysis: Questions, answers or statements, which clarify, explain, or develop additional information regarding a proposed solution.
   - Evaluation: Questions, answers or statements, which provide or seek a value judgment related to a proposed solution or a comparison of multiple solutions.
   - Decision: Statements related to conclusive decisions for or against a solution. The decision should be a final decision agreed upon by the entire group.
2. Technical communications: Questions, answers or statements, which focus on the use of the technology tools and applications.
3. Other: All other communications, which are not included in the previously defined categories. For example, students may discuss unrelated topics such as the weather or unrelated course information. Note that silence was excluded from all categories so there is no categorization of silence.

In this research, only the project related communications were analyzed. The content analysis result of the 10 videos is shown in the following table:

Table 1. Time Percentage Spent on Each Communication Categories of the Total Video Duration.

	Experimental Group	Control Group
Goal Clarification	5.09%	4.53%
Solution Generation	17.84%	11.12%
Analysis	65.73%	79.58%
Evaluation	7.92%	3.13%
Decision	3.42%	1.64%

Data shown above are the average for five groups in the experimental and control group. The time percentage table shows that the experimental group who use the VCS interface spent more time on clarifying their goals, generating solutions, evaluating proposed solutions and making decisions over the whole communication process. On the other side, they spent less time in explaining proposed solutions or develop additional information in order to solve the problem. The experimental group had a more effective group process since it was able to generate more solutions, evaluate them and make decisions. At the same time, they spent less time explaining solutions and developing additional information in order to solve the problem, which made the problem solving process more effective use of their time.

4.4.1.2 Group interaction

The group interaction was also examined since the researcher observed differences in the interactions between the control groups and experimental groups in the experiment. In the coding scheme, two types of group interaction are defined as:

1. Collaborative Interaction: Mutual engagement of students in a coordinated effort to solve a problem.
2. Cooperative Interaction: Division of labor so that different people are responsible for portions of the work.

The hypothesis for this research is that a collaborative process produces a more effective group learning experience since in collaborative interaction, all members in the group focus on the same topic and all of them learn more about that topic at the same time through discussions. In cooperative learning, each individual focuses on their own task, it is an effective way to finish a task faster, but it may not allow all members in a group to achieve a maximum learning experience.

Table 2. Collaborative vs. Cooperative Interaction Time Percentages.

Groups	Control Group (Commercial 4D)					Experimental Group (VCS)				
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Collaborative	44%	97%	98%	100%	100%	100%	100%	100%	100%	100%
Cooperative	56%	3%	2%	0%	0%	0%	0%	0%	0%	0%

Table 2 shows the time percentage each group spent on collaborative and cooperative interactions. Group 1 to Group 5 is the control group and Group 6 to Group 10 is the experimental group. We observed three out of five groups in the control group had cooperative interactions throughout the process. One group spent a significant amount of time using cooperative interaction (56% of the overall process). Though the other two groups did not have significant amounts of cooperative interaction, it was still important to note that no cooperative interaction was observed in any of the experimental groups.

4.4.2 Group product

For each student group, when they decided they had finished developing their schedule the first time in the experiment before they reviewed the 4D model, the researcher documented that schedule as an initial schedule. Both the quality of the initial schedules and the final submitted schedules were evaluated. The quality of the initial schedules was evaluated using a standard schedule evaluation rubric. Based on a 15-point scale, the average grade for the control group was a 10.40, and the average grade for the experimental group was a 10.58. The quality of the final submitted SIPS was compared between the two groups as well. Based on a 30-point scale, the average grade of the final SIPS for the control group was a 24.3, and the average grade for the experimental group was a 24.5. These increased scores reflect revisions that the students made after further reflection and analysis. These are not significant difference between the groups in overall quality, but it does indicate a small improvement using the VCS.

4.4.3 Student perceptions

A survey was used to compare students' perspectives of the two different interfaces. Survey results are shown in Table 3. These results show that students using the VCS interface (experimental group) felt that the 3D model was more valuable and fully utilized in helping them develop the schedule as compared to students using a traditional CPM and 4D interface. A larger percentage of students in the experimental group stated that the 3D model helped them generate ideas and evaluate other group members' ideas, keep group members focused on the same topic, and improved the overall team communication. These two interfaces had similar effects in making student group members feel confident about their initial schedules, and helping them examine their schedules. And, an important note for the educational side of the study, students using the VCS interface enjoyed the planning exercise more than students using the traditional 4D CAD interface.

5 CONCLUSIONS

This study investigated the effectiveness of 4D modeling used in construction engineering education for schedule visualization. The value of the 4D learning module was identified by examining group process, group product, presentation effectiveness, and student perceptions. 4D learning modules using two different 4D processes were compared. Both processes were found to be valuable for improving the students' learning experience. The additional interactivity in the VCS interface showed some additional value beyond the current 4D CAD application. When comparing the commercial 4D modeling module to the VCS module, it was noted that:

1. The group process was more effective using the VCS interface.
2. Both the quality of the initial schedule and the final schedule developed using the VCS interface were slightly higher than using a traditional 4D modeling interface, but the differences were not significant.
3. Significant difference was found in student perceptions towards these two interfaces. Students using the

VCS interface felt that they were able to generate more solution ideas, focused on the common topic more easily with other group members, and had better communications with their group members. The VCS groups enjoyed this experience more than the groups using the current 4D application. They felt they had more fun throughout the exercise.

Table 3. Student Perception Surveys from 2006.

Survey Questions	Average	Control (NavisWorks)	Experimental (VCS)	Difference (VCS-NW)
It was valuable to have a large scale 3D model when developing our schedule	4.41	4.13	4.69	0.56
Our group adequately utilized the 3D model when developing our schedule	3.75	3.31	4.19	0.88
The 3D model helped me in generating ideas and evaluating other people's ideas	4.06	3.81	4.31	0.50
The 3D model provided a common media to keep the whole group focused throughout the process of developing the schedule	4.09	3.94	4.25	0.31
I felt confident in the initial schedule that we developed before reviewing the 4D model in the ICon Lab	3.63	3.69	3.56	-0.13
The 4D model in the ICon Lab was helpful for examining the schedule we developed.	4.50	4.56	4.44	-0.13
I felt more confident in our schedule after reviewing the 4D model.	4.03	4.06	4.00	-0.06
The 4D modeling activity helped me gain a better understanding of the SIPS process.	4.00	4.06	3.94	-0.13
I enjoyed performing the exercise in the ICon Lab.	4.03	3.94	4.13	0.19
The 4D model made it easier for me to communicate with my team members when we worked on the assignment.	4.19	4.14	4.25	0.11

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