VIRTUAL FACTORY MODELS: DO THEY HELP STUDENTS LEARN?

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Abstract

Virtual models can be a useful tool when used to offer students an 'artifact' of industrial and manufacturing engineering by providing a simulated realistic environment. A virtual factory model was provided for students to view and interrogate a process to assess a key lean manufacturing concept. Students were presented with a factory cell and a 5S checklist. 5S is a principle of workplace organization that is central to the Japanese philosophy of Just-in-Time. This checklist was used to evaluate the organization of a work area (cell). Students interacted with the virtual model to assess the 5S rating of the cell. Then, students proposed improvements to the cell. Results from a pre- and post-test show that student learning increased with the virtual simulation and an industry-based project. This paper presents the virtual factory model and student performance in using the checklist and their application of lean manufacturing principles in proposing improvements.

Motivation

Case studies, in general, are considered helpful in student learning. However, this research asks the question, "do virtual case studies have an additional impact?" Students learn better when engaged, when they are involved in the process and can apply their learning [1,2]. Gorman, et al. [3] proposed that cases aid engineering students ability to apply classroom concepts to engineering practice. The more open-ended the application, the better suited the case study. Frequently, students can learn the concepts to pass a test or complete the homework assignment, but the students have not obtained the practical knowledge to perform the task. Therefore, case studies are developed to aid in preparing students to perform engineering tasks.

Background and History of Course

Virtual reality (VR) is beginning to be widely used in fields such as entertainment, medicine, military training, and industrial design. Virtual reality models of manufacturing systems have been used for quite some time; and range in complexity from the level of a single process on a single machine [4], to flexible manufacturing cells [5], to models of entire factories [6]. VR models are typically distributed over the internet using the Virtual Reality Modeling Language (VRML) format. As Ross and Aukstakalnis indicate [7], virtual reality is used in the engineering design process, so we should be incorporating virtual reality in engineering education.

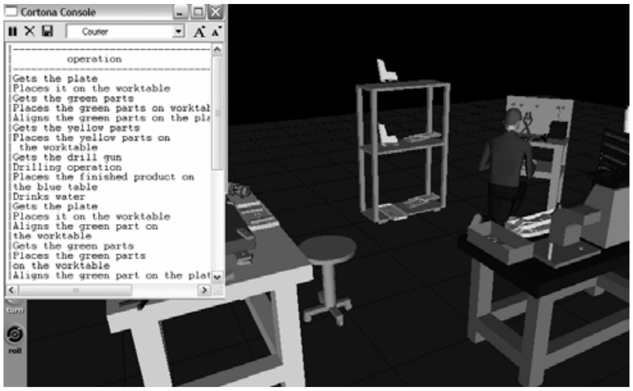
There are many interesting examples of the use of virtual reality in education. Jones et al. [8] discuss the use of virtual reality to present the results of simulations as a "super" graphical animation that will lead to an expanded role of simulation in decision-making and communication. Lefort and Kesavadas [9] have developed a fully immersive virtual factory testbed for designers to test issues such as plant layout, clusters, and part flow analysis. Many researchers [10-12] have discussed the use of large-scale simulations for studying the virtual behavior of factories. Virtual factories have also been used for simulation-based control of real factories [13], and for studying the interaction between business decisions and quality [14]. Impelluso and Metoyer-Guidry [15] use VR in engineering education to facilitate constructivist learning, a theory where individuals construct new learning from their experiences, and enable experimentation with design. Whitman et al. [16] discuss how a case study using a virtual model of the factory can address competency gaps in a curriculum.

Many students study a conceptual theory and believe they understand and can apply the concept. Frequently, when students are placed in a less refined environment to apply the concept, their ability to apply the concept is weak. Therefore, placing students in a real factory environment typically has a more practical impact. However, a problem with using a real factory environment is that if two students view a factory cell at two different times, their experiences may be totally different. A virtual model provides an opportunity for students to apply their knowledge in a less refined, yet consistent environment.

Lean manufacturing is a popular subject in industrial and manufacturing engineering to improve a system. One of the first aspects of lean manufacturing that most companies try to implement is the concept of 5S. 5S is a principle of workplace organization which is central to the Japanese philosophy of Just-in-Time. A transliteration of the 5S's are: Sort, Store (Set in Order), Shine, Standardize, Sustain. This paper describes the usefulness of a virtual factory model for student learning to apply 5S to a real environment. The next section discusses the method and the remainder of the paper focuses on the analysis of the pre-test and post-test results.

Method

Many virtual models have been developed at Wichita State University to improve student learning in Industrial and Manufacturing Engineering. The Lean Manufacturing course initially implemented two of these models. One model was of the assembly of a Boeing 767 strut. This model is useful for an overview of the line and a virtual factory tour. The other model, which is a detailed model of one cell in the line, has been used at Wichita State University (WSU) for many purposes. The cell shown in figure 1 has been used for demonstrating concepts such as batch sizing [17], work systems and lean manufacturing. Students, later in the semester, use the 5S checklist in an actual company and the experience with the virtual model better prepares the student for the 5S assessment.



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Gets the yellow parts
Places the yellow parts on
 the worktable
Gets the drill gun
Drilling operation
Places the finished product on
the blue table
Drinks water
Gets the plate
Places it on the worktable
Aligns the green part on
the worktable
Gets the green parts
Places the green parts
on the worktable
Aligns the green part on the plat
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Figure 1. Virtual Reality Assembly Model.

The Lean Manufacturing course in the Fall 2007 semester at WSU was used in this experiment. Forty-seven students from the Fall 2007 Lean Manufacturing class participated in this exercise (79% graduate/21% undergraduate). The procedures for this exercise consisted of lecture, followed by a class exercise, a pre-test, completion of a virtual model 5S assignment, industry-based project followed by a post-test. The class exercise was simple, but prepared the student by requiring the student to reflect on each of the 5S concepts and to apply to a common situation. The lecture, delivered by one of this papers author, consisted of an introduction of 5S concepts, presentation and description on how to use a 5S audit checklist.

The pre-test contained both content knowledge questions and attitudinal questions. The exact questions are shown in Tables later in the paper with the results of the student responses. Below is a summary of the types of questions:

- Multiple-choice questions on content knowledge about the 5Ss (questions 1-5),
- Essay question requesting an example of a visual control (question 6),
- Essay question determining the students' ability to articulate the need for 5S (question 7),
- Multiple-choice questions about the effectiveness of the 5S class exercise (questions 8-13).
- Multiple-choice question about how easy or difficult 5S is to implement (question 14),
- Question requesting a prediction as to how many times they would view the virtual simulation.

After completion of the pre-test and the class exercise, students could install a VR model viewer (Cortona by Parallel Graphics which is available for free [18]) or they could view the model in one of the computer labs on campus. The actual VR assignment consisted of installation, observation, rating and a report. The students were asked to observe and interact with the VR model. Students then were to use a provided 5S checklist to provide a 5S rating. For example, the checklist for item, "1.2 Removing Unnecessary Items" states that, "All items not necessary for performing work are removed from the workplace. Only tools and products are present at the workstations." This item, and all items, was scored by the student according to table 1. The student then sums the score in each of the 5S's. A radar chart was typically developed as shown in figure 2. The radar chart shows a Sort rating of 1.33, a Storage rating of 1.83 and a Shining rating of 2. This graphically shows the current state of the workplace organization (5S). The higher the rating, the better the workplace. Students then write a report containing the assessment and a plan for improvement. The next section describes the virtual reality model and how it is used. Students submitted a report with a plan of action for the cell with multiple specific ideas.

Table 1. 5S Assessment Levels.

0. Unacceptable, Zero Effort
1. Activity Started, Slight Effort
2. Widespread Activity, Many Opportunities for Improvement
3. Minimum Acceptable Level, Sustained for at Least One (1) Month
4. Best in Class, Results Sustained for Three (3) Months
5. World Class Example, Sustained for at Least Six (6) Months

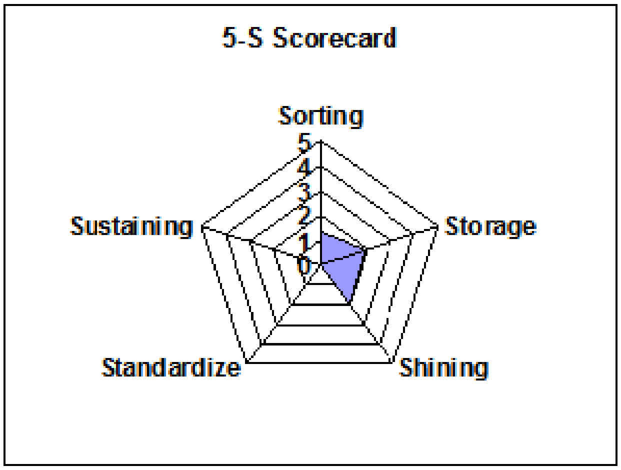

Figure 2. 5S Radar Chart.

Finally, students completed a post-test about 5S. The post-test was similar to the pre-test except for the following:

- Essay question requesting an example of a visual control (question 6) requested a specific example from the class project,
- Essay question determining the students' ability to articulate the need for 5S (question 7) requested a response for a specific audience (project sponsor versus a generic project manager in the pre-test)
- Essay question requesting a prediction as to how many times they would play the virtual simulation was replaced with a multiple-choice question asking if the virtual simulation helped them on their project.

Virtual reality model

The virtual reality model developed for this effort is about a worker performing a setup and assembling a part. A snapshot of the model was shown previously in figure 1. The model can be viewed using the previously mentioned Cortona viewer on the Wichita State University server [19]. The model was developed using IGRIP with imported CATIA geometry for the parts. An actual factory worker was observed to develop the model. The actual process was slightly modified to provide more opportunity for student's to propose improvements to the workplace.

Results

The first five questions were simple multiple-choice questions concerning concept knowledge about the 5S's. Mean scores for the five content questions are shown in Table 2. Content knowledge was significantly increased in the post-test (paired t-test with a $p < .001$) for questions 1 and 2. Question 3 was not significant (at the $p > .05$ level) as the initial scores on that question were already fairly high. For question 4 there was significant improvement (at the $p < .01$ level). For content questions 1 through 4, the post-test questions resulted in good knowledge comprehension (96%, 100%, 100% and 89% correct answers). However, for both the pre and the post-test responses, question 5, "Which of the 5S's make a habit of properly maintaining correct procedures?" was confused by many students with almost all of the students answering "Sustain" which is the incorrect answer ("Standardize" is the correct answer). Question 6 was an essay question asking the student to provide an example of a visual control. The instructor scored the essay question based on the detail of the example (a wrong example provided received a zero, a weak example received a '0.5' and a good example received a '1.0.') Students were marginally better able to provide an appropriate example after the project.

Table 2. Mean scores (SD) test responses for questions 1 through 6 (Content knowledge).

(1 is a correct answer)	Pre-test	Post-test
Which of the 5Ss "removes unneeded items from the workplace." ***	0.69 (0.22)	0.96 (0.04)
Which of the 5Ss asks, "Where should I locate this item?" ***	0.77 (0.18)	1.00 (0.00)
An outline of a tool displaying where the tool should be placed when not in use is called:	0.94 (0.06)	1.00 (0.00)
Why is the 5S aspect shine important? **	0.70 (0.20)	0.89 (0.08)
Which of the 5S's make a habit of properly maintaining correct procedures?	0.38 (0.24)	0.44 (0.25)
Provide an example of a visual control *	0.78 (0.16)	0.96 (0.02)

*** significant at the $p<0.001$ level
** significant at the $p<0.01$ level
* significant at the $p<0.05$ level

Question 7 was an essay question asking the student to convince the plant manager to implement 5S (two paragraphs or less). In the post-test, students were asked to convince their project sponsor. The project sponsor was the company contact for the student industry based project. The instructor again scored the essay question based on the quality of the example (a wrong example provided received a zero, a weak example received a '0.5' and a good example received a '1.0.') Students significantly ($p<.0001$) increased in the ability to respond to this question, but the average changed from 0.28 to 0.60 which still should be improved.

Questions 8 through 11 were student perception questions requiring the student to respond if the class exercise was effective in helping students. None of the responses were significantly different ($p < 0.05$ level) except for the improvement of problem solving skills as shown in table 3. This likely indicates that students find a case study effective in developing these skills and appreciation. The virtual simulation was created in a manner that makes it difficult for the student to identify improvements.

Table 3. Mean scores (SD) test responses for questions 8 through 11

(1 = not effective; 5 = very effective)	Pre-test	Post-test
Effective for developing skills to handle engineering tasks	3.89 (1.05)	4.10 (0.62)
Effective for linking theory to real world	4.12 (0.90)	4.21 (0.52)
Effective for improving problem-solving skills*	3.44 (1.08)	3.93 (0.93)
Effective in developing appreciation for when 5S is applicable	4.19 (0.77)	4.34 (0.49)

* significant at the $p < 0.05$ level

Question 12 asked how willing the student would be to do a lean project without the 5S exercise and Question 13 asked how willing the student would be with the 5S exercise. Question 12 and 13 were paired on each test (pre and post) and compared. The two-tailed t-test showed that there was a significant increase in perceived ability (at the $p < .001$ level) for the pre-test questions. There was an even greater significance at the post-test questions. An analysis of the responses for question 14 showed there was no significant difference in how difficult students perceived 5S implementation. Question 14 was multiple choice (hard, not easy, moderately easy, easy).

The final question on the post-test asked students if the virtual simulation helped them on their industry-based project. Figure 3 shows that most students perceived that the virtual simulation was helpful on their industry-based project.

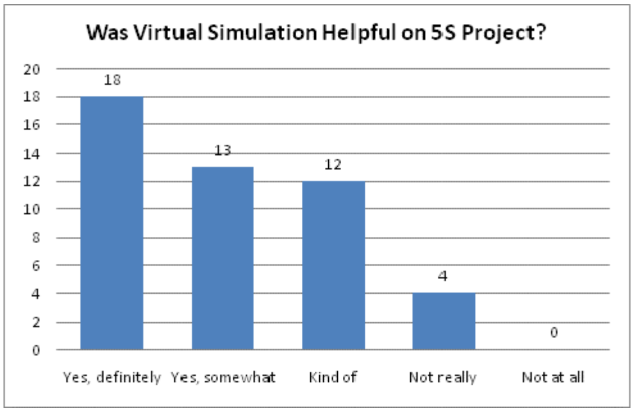

Figure 3. Perception of Usefulness of Simulation (# of students).

Summary and Future Directions

Comparison of the pre-test and post-test showed that student content knowledge increased after the virtual simulation and project. Two of the 5Ss, standardize and sustain, are confused by many students and this should be better described with more realistic examples. Student ability to articulate the need for 5S was significantly increased, but there remains room for improvement. The effectiveness of the simulation was significantly better than the in-class exercise although the effectiveness is high in both cases. The last set of questions demonstrated that the students perceived that the virtual factory model was effective in completing their project.

For future classes, a varied method will be used to improve the usefulness of the results. There will be three tests. The first test will be after the in-class exercise. The second test will be after the simulation. The final test will be after the project.

Virtual reality holds the potential to “bridge the gap” between in-class theory and “on the shop floor” reality. Only when a virtual factory model is well designed and implemented can it truly realize the potential to increase student learning at all levels.

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