Kong, S.C., Ogata, H., Arnseth, H.C., Chan, C.K.K., Hirashima, T., Klett, F., Lee, J.H.M., Liu, C.C., Looi, C.K., Milrad, M., Mitrovic, A., Nakabayashi, K., Wong, S.L., Yang, S.J.H. (eds.) (2009). *Proceedings of the 17th International Conference on Computers in Education [CDROM]*. Hong Kong: Asia-Pacific Society for Computers in Education.

Using Simulations to Enhance Learning and Motivation in Machining Technology

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Abstract: Recent advances in technology have introduced new tools to enhance learning. In the context of polytechnic education, simulation based learning (SBL) has been used to improve learning and motivation of engineering students studying Machining Technology in the Mechatronics course. This study investigates the effect of SBL on students' learning and motivation in a practice-oriented topic. In the study, students in the control group received conventional instructions and workshop practices while students in the experimental group had an additional component on SBL in the laboratory. Both groups, however, received an equal amount of time on the subject. A post intervention test followed by a survey was administered at the end of the study. This paper highlights the findings from both instruments, showing that SBL can improve student learning outcomes as well as the motivation to learn.

Keywords: simulation-based learning, learning from digital media, motivation, engineering

1. Introduction

A simulation environment closely resembles the physical system while allowing learners to explore situations not possible with actual systems [1]. They are usually interactive visualisations which allow learners to change input variables by entering data or by manipulating visual objects to observe the consequences of these changes via numeric displays, text labels and even changes in the visualisation environment. Simulation-based learning (SBL) is widely used in industrial training programs and in educational programs to enhance textbook and theoretical learning. Research suggests that SBL is generally effective in achieving greater knowledge gains [2]-[3]. In engineering education at the tertiary level, the use of computer simulation to enhance student learning process and understanding has been well documented in a variety of contexts ranging from skill transfer, collaboration, to problem solving and performance [4]-[7]. However, there were fewer studies on the effect of computer simulations on student's motivation to learn, especially for post secondary engineering education at the polytechnic level. In Singapore, students have a variety of choices when considering post-secondary education. On the average, about forty percent of secondary school leavers opt to further their studies in the polytechnics. Polytechnics have a strong focus on practice-oriented learning, skills training and on the preparation of their students for the world of work. This article will highlight findings from a study on the use of simulation-based learning (SBL) to improve the learning and motivation of engineering students enrolled in the Mechatronics course.

According to Tan [8], in his work on virtual environments, careful attention should be given to choosing a topic for such implementations. This is because visualisation can have a negative impact on learning because of its distracting nature. In this study, the topic Machining Technology was chosen. Students learn the fundamentals of machining, including the features, functionality, operations and processes. As such, there is a need for them to visualise how the machine is constructed, how the various components in the machine moves and how the various manufacturing operations are carried out. Course instructors often observed that students have difficulties using machines such as the lathe, milling, sheet-mental bending and shearing machines. One reason could be that they were intimidated by the complexity and size of the machine and secondly, they could not remember the complex functionality of the machines. Hence, it was felt that the introduction of interactive 3D machine simulations could augment student learning by enhancing confidence and their mastery of the required knowledge and skills. There would be modules for exploring the various machines and their components, modules for rehearsal of machine operations, modules for combination of different machine operations, as well as assessments. Screen captures of the SBL modules are shown in figure 1. This paper is part of a larger study on SBL and will present findings from two instruments, mainly a post intervention test and a survey.

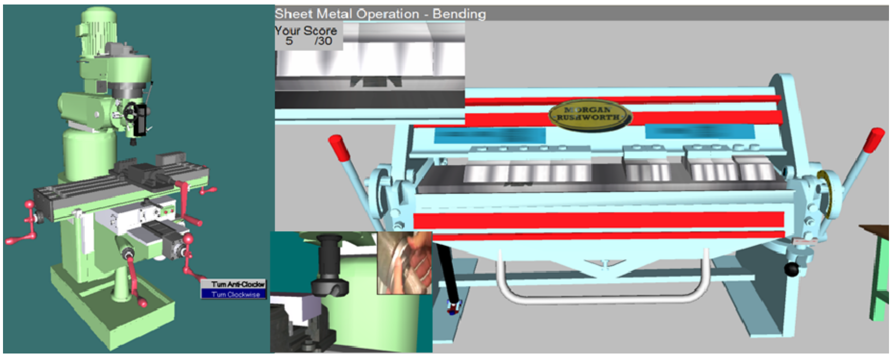


Figure 1. Sample SBL Modules

2. Method

2.1 Participants

Out of 126 students in the cohort, 114 students aged between 17-37, having a mean age of 21.2 took part in the study. Those not included were students who were repeats, had switched class during the course of the study or had switched from similar courses at the same level in other polytechnics. Sampled students were attending year 2 of the Mechatronics Engineering course in Temasek Polytechnic. The sample, consisting of 83 male and 31 female were drawn from the same pool that is, students who passed the common year 1 examinations. The sample was further broken down into two groups, a control group (Group C) consisting of 45 students (31 male, 14 female) and an experimental group (Group E), consisting of 69 students (52 Male, 17 female). A t-test, carried out to assess the equivalence of the groups in terms of academic ability, showed no statistically reliable difference between the mean Cumulative Grade Point Average (CGPA) scores between the C ($M=2.977$, $SD=.779$) and E ($M=3.205$, $SD=.896$) Group students, $t(112) = 1.398$, $p = .165$ (two-tailed), equal variances assumed (Levene's test, $p>.05$).

2.2 Intervention Procedure

Over a 6-week duration, both group C and E students undertake 24 hours of lessons at 4 hours per week. Whilst group C students undertake a lecture and workshop combination, at 2-hour per session respectively, group E students took 1.5 hour of lecture, .5 hour of laboratory using SBL, followed by 2 hours of workshop practice. Both groups visited the workshop in week 1 to allow them to form associations between workshop practices and theoretical studies. In week 7, a post intervention test was conducted over a half-hour session. This was followed by a survey questionnaire. Students from both groups attempted the 47 Likert-based items. In addition, E group students attempted 4 additional open-ended questions. Additional questions identified from the survey were put to 15 selected students during an informal conversational session the next week. This helped to clarify vague or puzzling replies from the students.

2.3 Instruments

The post intervention pen and paper test required students to apply and to synthesise their knowledge on machining operations. It comprises a question that tested how students would produce a common part that require machining processes from different machines. Students could illustrate their plan in a sketch, flow chart, table or a combination of these. The test was marked blind by a subject tutor. This performance test was identified as one indicator of effectiveness. To understand students' motivation when they use the SBL modules, a survey questionnaire was adapted from a framework based on self-determination theory (SDT). The questionnaire also included items on students' use of cognitive strategies, modified from Pintrich & De Groot [9]. Students from both the C and E groups took a survey questionnaire consisting of 47 five-point Likert based items. Item scoring was based on a 5 point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The learning subscales are: self efficacy, self regulation and cognitive strategy use. The psychological needs subscales are: perceived autonomy, perceived competence and relatedness. The motivation subscales are intrinsic motivation, external regulation, introjected regulation, identified regulation and amotivation. Table 1 shows the details. The additional 4 items posed to Group E students were questions that allowed students to put in their own words, what they liked or disliked about using SBL and whether they were able to learn from the modules.

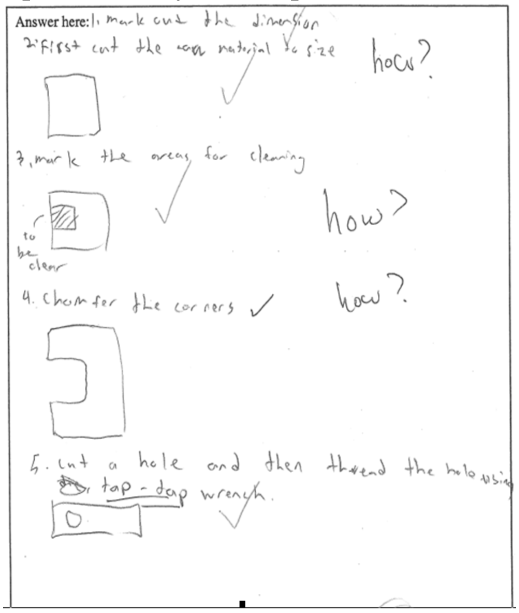
Table 1. Survey Subscales

Subscales	Items	Adapted from:
Self efficacy	6	Self Efficacy Scale (GSE) [10]
Perceived autonomy	5	Learning Climate Questionnaire [11]
Perceived competence	5	Intrinsic Motivation Inventory [12]
Relatedness	3	Intrinsic Motivation Inventory [12]
Intrinsic motivation	5	Academic Self-Regulation Questionnaire [13]
Self regulation	4	Self Regulated Learning [9]
Cognitive strategy use	8	Self Regulated Learning [9]
Extrinsic motivation :		Academic Self Regulation Questionnaire [13], adapted Harter's [14] Scale for measure of individual differences in motivation [15]
- External Regulation	2	
- Introjected Regulation	2	
- Identified Regulation	4	
- Amotivation	3	

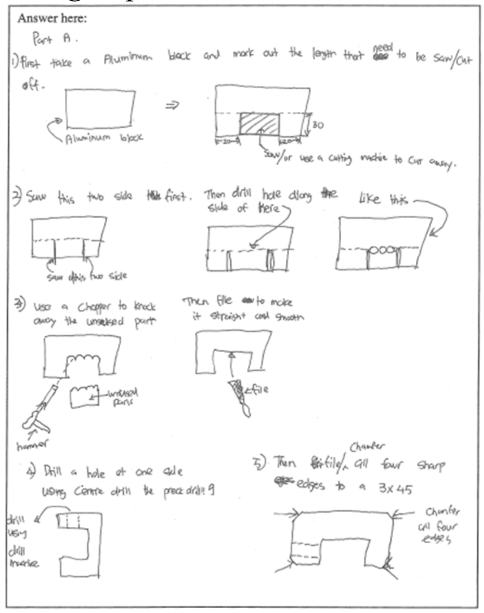
3. Results

3.1 Post Intervention Test

In total, 113 students attempted the test (1 being absent). There were 45 students in Group C and 68 students in Group E. An equal variances t-test showed that there was a statistically reliable difference between the mean post intervention test scores of the C Group (M=3.478, SD=2.538) and E Group (M=4.441, SD=2.494) students, t(111) = 1.996, p = .048, (two-tailed). The effect size at .384 can be considered a medium value *given that only .5 hour of a 2-hour session was given to using SBL. The interquartile range for Group C students was larger (4.0), indicating that Group E students (2.0) have less variation in the understanding of the topic. The highest score in Group C was 9 compared to 10 for Group E. The lowest score for both groups was 0.*



Sample from Control Group



Sample from Experimental Group

Figure 2. Sample student answer scripts

Figure 2 shows sample answer scripts from the post intervention test. Scripts from the experimental group were found to be richer in terms of the detailed information. For example, students were able to show the correct terminology, sequence of operations, the key practical aspects of alignment for accuracy and finally, finishing whereas students from the control group was only able to list the operations but were unable to use the correct terms or give details of work.

3.2 Survey Questions

A total of 114 students took part in the survey, 45 from the C Group and 69 from the E Group. Table 2 shows the mean and standard deviation for the different subscales in the survey, re-organised into the three categories of learning, psychological needs and motivation. The analysis on learning was taken from the self efficacy, self regulation and cognitive strategy use subscales, consisting altogether 18 items. Self efficacy is the belief that one can perform a novel task or cope with difficulty. Perceived self efficacy facilitates behaviour such as persistence, effort investment and self regulatory behaviour. Self regulation includes students' metacognitive strategies for planning, monitoring and modifying their cognition, as well as management and control of their effort on tasks. Students use different cognitive approaches such as elaboration, rehearsal, and organizational strategies to help them learn, remember and understand. Table 2 shows that E group students perceived that they have higher self efficacy and self regulation but use less cognitive strategies. However, further analysis of the individual items in the cognitive strategy use subscale showed that although these students perceived that SBL helped them in connecting concepts and enforce rehearsals, students perceived SBL to be harder to learn from as they had to tediously work through the tasks in the software. As the method was still new to them, E group students also felt less confident that the software can indeed replace their study material. This is also consistent with feedback from students during the informal conversation sessions.

Table 2. Mean, SD and Alpha Coefficient

		C Group		E Group		
	Subscale	M_C	SD_C	M_E	SD_E	Alpha
Learning	Self Efficacy	3.67	0.55	3.78	0.57	0.76
	Self Regulation	3.26	0.64	3.42	0.71	0.75
	Cognitive Strategy Use	3.67	0.44	3.62	0.61	0.79
Psychological Needs	Perceived Autonomy	3.85	0.46	3.58	0.65	0.76
	Perceived Competence	3.74	0.72	3.82	0.64	0.86
	Relatedness	3.50	0.81	3.58	0.71	0.78
Motivation	Intrinsic Motivation	3.88	0.80	3.73	0.69	0.83
	External Regulation	2.71	0.90	2.54	0.99	0.60
	Introjected Regulation	2.21	0.84	2.40	0.91	0.73
	Identified Regulation	4.04	0.58	4.03	0.61	0.73
	Amotivation	2.33	0.85	2.22	0.82	0.75

Learner motivation is enhanced and becomes more self-determined when the three basic psychological needs for autonomy, competence and relatedness are satisfied, according to SDT [16]. The results from these subscales, consisting altogether 13 items, showed that students in the E group perceived that they have less autonomy support but higher levels of competence and relatedness compared to students in the C group. Feelings of competence are important because they facilitate the students' goal attainment and provide a sense of satisfaction from engaging in an activity at which they feel effective. This is also consistent with Group E students' response to self efficacy items where they showed strong belief in their ability to handle difficult tasks. Here they draw satisfaction from their ability to complete an activity given to them. The need for relatedness is satisfied when students feel that they are accepted and valued by their peers and instructors within the learning environment. According to SDT, students perceive their need for autonomy support to be satisfied when they are granted an acceptable degree of volition and independence in their learning. In this study, students perceived that a number of their suggestions were discounted by the instructors. The situation arose because after going through the SBL modules, student felt that they could make some changes to the process. However, the instructor's view was that students should not deviate from safety procedures.

Group E students perceived that they were less intrinsically motivated compared to Group C students. The 5 items used in this subscale assessed the students' interest, enjoyment, effort, and tension during learning. Group E students gave lower scores as they felt pressurised due to perceived need for more time to go through the exercises in the SBL modules. Students also gave reasons such as the effort needed to "mine" information from the software. In the study, 11 items in the various extrinsic motivation subscales were used in the study. Extrinsic motivation is perceived to exist as a continuum of increasingly self-determined behaviour [17], ranging from external regulation (least internalised) to identified regulation (most internalised). Internalisation leads to more autonomous behaviour. E group students perceived that they have a lower level of external regulation but higher level of introjected regulation compared to their peers in the C group. External regulation is behaviour that is externally reinforced. Care should be taken when interpreting results from this subscale as it has an alpha value of .6. The alpha is used to assess the internal consistency of the items (usually a value of .7 and above is acceptable). Introjection refers to behaviour that is prompted by guilt avoidance or ego enhancement. It was felt that students wanted to do well due to being part of the experiment so as to gain some imagined approval and they put pressure on themselves.

Compared to the C group, E group students have a higher mean value. This was consistent with their replies in the intrinsic motivation subscale where they perceived more tension and pressure and complained about having to "mine" for information. This finding is also consistent with Ryan & Deci [17], where it was found that introjected regulation was related to more anxiety and to poorer coping skills. It is also consistent with their feedback on feeling less confident learning from the software although they perceive that they have higher self efficacy and self regulation. Identified regulation refers to accepting values as personally important. Both groups of students have almost the same mean value for identified regulated behaviour ($M_C = 4.04$ vs. $M_E = 4.03$). Students are said to be amotived when their behaviour lacks intentionality and a sense of personal causation [17]. Students in the E group are less amotivated compared to the C group. It was noted that students felt that the interactive aspect managed to arouse more interest than merely reading about the information on paper. The overall scores for the E Group were not significantly different from those in the C Group. Further analysis of individual subscales (table 2) showed significant differences only in the perceived autonomy subscale $t(112)=2.40$, $p=.02$, $d = .46$. A comparison of the mean and standard deviation between the C and E group is shown in table 2. A Cronbach's alpha test showed that all the components in the study were consistent (with a value of more than .7) except for external regulation which has a value of .60.

The 4 open-ended questions in the survey revealed that 85.5% replied positively when asked the question "Was the simulation-based digital representation of the machines and machine processes useful in aiding your understanding of the subject?"

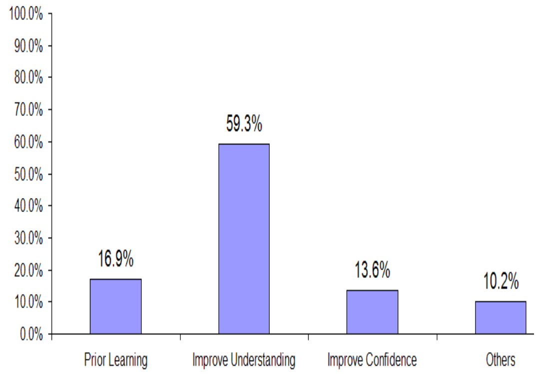


Figure 3. How digital replicas of machines helped student learning

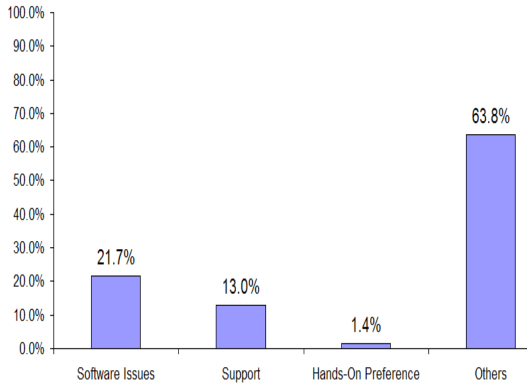


Figure 4. Features that students disliked

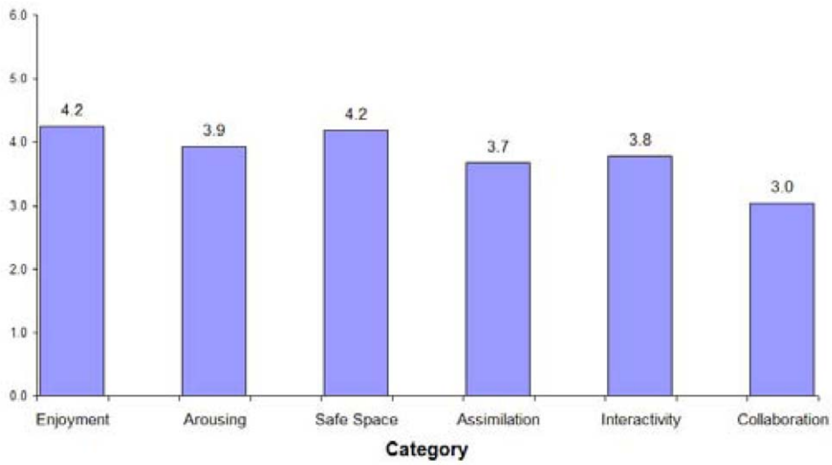


Figure 5. Useful features incorporated into SBL

For those who replied positively, 59.3% commented that SBL helped them to understand the topic under discussion better. 16.9% commented that SBL helped them to prepare for their workshop tasks before they started the hands-on sessions. 13.6% said their confidence was improved after going through the system. This is illustrated in Figure 3. When asked, "What was the one thing you least liked about learning from a simulation environment?", 21.7% of respondents felt that the software itself could be improved in terms of loading time, procedures, functionality, realism and the user-interface. 13% of respondents felt that there should be more support given in terms of access and technical. 1.4% felt that it was not useful as they prefer learning on the shop-floor directly instead of exploring SBL first. Figure 4 illustrates this. When asked "Do you think the use of such simulation based digital models of learning will help you learn better in your other subjects?" 87% replied positively and suggested several practice oriented subjects such as programmable automation, microcontroller technology, dynamics and robotics. When asked to rank the important features of the SBL software, respondents listed "safe space" and "enjoyment" as key useful features. "Safe space" allowed them to learn without their fellow students commenting on their learning, as well as in terms of safety where they can afford to make mistakes. "Enjoyment" allowed students to move towards learning that comes from intrinsic motivation. The ranked features are shown in Figure 5.

4. Concluding Discussion

In terms of performance, group E students' test scores were higher. They appear to have less variation in their understanding of the subject and achieve better retention of details. More than 85% in the E group students felt that SBL was useful in helping them to learn. They felt SBL helped them to improve their understanding of the topic, allowed them to have prior engagement with the machines even before they walk into the workshop and improved confidence in their learning of the subject. This could in part be related to the various features available in SBL which helped them to rehearse, build their confidence, allow a "safe" environment, provide enjoyment and helped them to collaborate through discussions using the simulation as a reference. In terms of psychological needs, although E group students perceived that they were competent and had higher scores in relatedness, they believed that they had less autonomy support. Correspondingly, this group of students had lower intrinsic motivation scores. The reason given was that they had to work harder to retrieve information from the modules, leading to insufficient time spent on the topics. Hence they felt less confident that they will be able to do better than their peers. The students' score in the learning subscales showed that Group E students had higher scores in self efficacy and self regulation but weaker scores in the use of cognitive strategies. Students found that SBL promoted self regulatory behaviour through strategies embedded into the modules, such as reflection, assessment in a "safe" environment hence improving their self efficacy and competence. However, low autonomy support, low intrinsic motivation lead to introjected related behaviour and low use of cognitive strategies. Analysis of the individual items in the use of cognitive strategies showed that SBL helped E group students connect concepts and associations. However, students perceived that SBL was harder to learn from and that they may not have used many of the learning strategies. One reason could be that SBL often use multiple representations such as animation, video, audio, texts and symbolic representations. Students may not be able to systematically relate these multiple representations. As a result, they fail to integrate the representations into a coherent mental model. In terms of learning and motivation, findings show that students perceived they were competent, related to their peers and instructors, exhibited self regulatory behaviour and self efficacy, but perceived they have less autonomy support and are not intrinsically motivated. Such students could attribute their maladaptive coping skills to having insufficient time to do their work, having to "mine" for information, to instructors rushing them on their work and to instructors not giving them enough autonomy in the workshops. Both groups seem to exhibit similar identified regulatory behaviour, suggesting that both groups accept that learning the topic have some personal value to them. The mean value for identified regulation is highest in both groups, suggesting that the students identified that the subject being covered was important for them. Students in the survey felt that they were able to associate concepts between the virtual simulation and the physical machines as well as the operations the machine could perform. SBL allowed "rehearsal" and students were able to assess themselves in a "safe" space where they could afford to make "trial and error" mistakes. These aspects promoted self regulation and self efficacy. The results provided a useful linkage between student learning in SBL and their motivation.

Acknowledgements

The work reported in this paper was supported by the Ministry of Education, Singapore and National Research Foundation, Singapore through the IDM in Education Grant, NRF2007-IDM003-MOE-004. We would also like to thank various colleagues, Fong FM, Lye SL, Kan D, Kwok M, Thwin MM and Chong WM for their assistance.

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