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Reviewing Simulation-based Learning at Temasek Polytechnic Through An Evaluation Framework

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Abstract

When Temasek Polytechnic's School of Engineering embarked on a research project to investigate the effects of Simulation-based learning on second year Mechatronics students, multiple qualitative and quantitative studies were carried out simultaneously. The intervention was an infusion of a suite of five Simulation-based learning (SBL) modules into the curriculum for three of five Machining Technology classes in the October 2008 semester. The individual studies highlighted the positive effects of this intervention. A model for SBL was even developed based on the results and findings of the multiple studies. This paper uses the Kirkpatrick Learning Evaluation Model as a framework to review the effectiveness of SBL for Machining Technology. Only three of the four levels of learning, namely response (Level 1), learning (Level 2) and behavior (Level 3) are involved. The results and findings of the various studies will be clustered and compared according to these levels to derive a more consolidated understanding of the effectiveness of SBL.

Keywords: Engineering education; Evaluation model; Simulation-based learning

1. Introduction

In 2008, Temasek Polytechnic, Singapore embarked on a major research project on the effectiveness of Simulation Based Learning (SBL) for Machining Technology. A suite of five SBL modules were placed on Blackboard 6 as supplementary online materials. Four modules focused on parts and processes for milling, drilling, turning and sheet metal and one to prepare students for their two workshop projects. A total of 114 second year Mechatronics students between the ages of 17 to 37 were involved in the research project. They hailed from Singapore, China, Myanmar, India, Sri Lanka and Malaysia and had different educational backgrounds. Some had more academic training while others, more technical training. They also had varying competencies in their command of English.

In order to ascertain the effectiveness of SBL, three classes enrolled in this subject had their curriculum infused with SBL. These formed the Experimental Group (E Group) while the other two classes formed the Control Group (C Group). An equal variances 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 participants in the C (M=2.977, SD=.779) and E (M=3.205, SD=.896)

Groups, with t (112) =1.398, p = .165 (two-tailed), equal variances assumed (Levene's test, p>.05). From there sub-sets were sampled for the respective studies.

The subject was delivered in English over a 15 week semester. The weekly schedule of the C Group comprising non-SBL participants comprised two hours of taught class followed by two hours of workshop practice. The curriculum of the E Group comprising SBL participants was modified in weeks two, four and six. They received one and a half hours of classroom instruction, followed by 30 minutes of self-instruction with SBL prior to their workshop practice. They also had 24/7 access as the materials were placed on Blackboard 6. Both groups visited the workshop in week one to allow them to form connections between workshop practices and theoretical studies.

The researchers planned a comprehensive agenda to capitalize on research funding from the Singapore National Research Foundation. In order to understand the effectiveness of SBL as a learning tool, they looked at the experiences of SBL participants and investigated how learner characteristics played a part in learning. They aimed to find SBL features that impacted learning and interactive experiences that assisted learning as well as identify the pre-conditions that would lead to the effective implementation of SBL. They also wanted to know if participants were able to perform better with SBL. As a result, multiple qualitative and quantitative studies were conducted simultaneously (Fang, Tan, et al., 2010).

The results and findings from the respective quantitative and qualitative studies pointed to the positive intervention of an infusion of SBL into the curriculum. They enabled a model for SBL to be developed (Tan, Koh, Fang, Tan, & Wee, 2010). However, there has been no attempt to review the studies together to derive a comprehensive understanding of the effectiveness of SBL for Machining Technology. This paper attempts to that using the Kirkpatrick Learning Evaluation Model (1994).

2. Kirpatrick Evaluation Model

Kirkpatrick's (1994) Evaluation Model provides a systematic and comprehensive approach to evaluate the impact of training programs. It focuses on aspects of learning at four levels. Kirkpatrick & Kirkpatrick (2005) describe these as follows:

- Level 1 is concerned with learner reaction to the training program and the satisfaction derived from attending the program. This provides important feedback and indications for further improvement. Reactions can be measured using a form to collect written comments.
- Level 2 focuses on the extent learning has occurred during the program in terms of understanding concepts, principles and techniques, developing new skills or improving existing ones, and the changing of attitudes. This requires measurement before and after the training. A paper-and pencil test could be used for measurement of knowledge and attitudes and a performance test for skills. The comparison the experimental group with the control group would provide more evidence on the impact of the training program for reaction.
- Level 3 investigates the transfer of learning and the extent on-the job behaviour has changed. This involves capturing the change in behaviour where possible by pre-post-tests, as well as a survey or interview with trainees and/or their bosses.
- Level 4 examines the results of the training. Measurement should be done before and after the training at appropriate times, allowing time for possible results to take place. If possible, a control group could be included.

Although the Kirkpatrick Model (1994) was designed to evaluate face-to-face training, Horton (2006) posits that it is possible to apply it to e-learning training as the outcomes evaluated reside with the learners.

3. Methodology

The Kirkpatrick Evaluation Model (1994), frequently used for face-to-face training programs was used to review the effectiveness of a simulation-based learning program in an educational institution. Only three levels of learning, namely, Response (Level 1), Learning (Level 2) and Behavior (Level 3) were included in this paper because the data for the fourth level was not collected for the SBL study. The research questions were as follows:

- How did the SBL participants relate / react to the SBL modules? (Level 1)
- Did SBL make a different in learning? What types of learning took place? (Level 2)
- Were the SBL participants able to transfer their learning to workshop practice? (Level 3)

The results and findings of the respective quantitative and qualitative studies from the Temasek Polytechnic SBL research project were compared in terms of these three levels of learning. It would have been better to design a study based on this model and use consistent groups for each of the levels. However, this approach, despite its limitations, allows the research team to relook the results or findings from these studies so as to garner new insights, y viewing the effectiveness of SBL from yet another angle.

Background information of all participants was collected in week 1. Formative SBL tests scores were collected in weeks two, four and six followed by observations of selected SBL and non-SBL participants during workshop practice sessions in the same weeks. In week 7, a post-intervention test was conducted over a half-hour session. This was followed by a survey questionnaire. Participants from both groups attempted 47 Likert-based items. The E group students attempted 4 more questions which were open-ended in format. Interviews with selected participants and teaching staff were carried for four weeks starting week 7 and this included the term test and term break weeks. The instruments to evaluate the different levels of learning are summarised in Table 1.

Instruments	Level 1	Level 2	Level 3
Blackboard statistics	Login data of SBL participants		
Online formative tests		SBL procedure test for Turning, Sheet Metal & Milling for SBL participants	
Pen & paper summative test		Post - intervention test for all participants	
Pen & paper survey	Participant's reaction to learning with / without SBL		
Pen & paper observation checklist			Observation by domain expert for selected SBL & non-SBL participants
Face-to-face interview	Semi-structured interview with selected participants		Open ended interview with staff

Table 1 – Instruments for Levels of Learning.

4. Comparison of Findings/Results

4.1 Response (Level 1)

Evidence for response came from usage of SBL modules on Blackboard, a survey of all participants and interviews with selected participants. SBL appealed to participants in many ways. These resulted supported qualitative and quantitative studies.

The findings from the qualitative study by Fang, et al. (2009) on engagement involving 18 Singaporeans suggest that SBL lessons that were of most immediate use, were integrated, and visually appealing engaged the participants most. In addition, the novelty of the experience, the thrills and challenges of online interactivity, and the appropriate use of multimedia, resulted in cognitive and affective engagement. However, there were requests for more flexibility in navigation, learning and testing, a greater emphasis on safety and 24/7 access to the materials. Fang, Tan, Thwin, Tan & Koh (2011) also found that the 18 Singaporean participants generally valued SBL for its ability to enliven learning of the subject and promote autonomous learning.

The quantitative studies showed that SBL improved the motivation to learn (Tan, et al, 2009, Koh, et al., 2010). The self-determination theory (SDT) was used as a theoretical framework for the assessment of student motivation. It posits that motivation becomes more autonomous when students perceive their psychological needs to be satisfied. Following the application of SBL, a 47-item survey was conducted in week 7. Item scoring was based on a Likert scale rating ranging from 1 (strongly disagree) to 5 (strongly agree). See Table 2 for items in the survey to investigate their perceived needs satisfaction, motivation and learning approach.

Subscales	Items	Adapted from
Autonomy Support	5	Learning Climate Questionnaire (Williams & Deci,1996)
Competence	5	Intrinsic Motivation Inventory (McAuley, Duncan & Tammen,1989)
Relatedness	3	Intrinsic Motivation Inventory (McAuley, Duncan & Tammen,1989)
Amotivation	3	Academic Self Regulation Questionnaire (Ryan & Connel, 1989), adapted Harter's (1981) Scale for measure of individual differences in motivation (Lepper, Corpus & Iyengar, 2005)
External Regulation	2	
Introjected Regulation	2	
Identified Regulation	4	
Intrinsic Motivation	5	Academic Self-Regulation Questionnaire (Ryan & Connel, 1989)
Self Efficacy	6	Self Efficacy Scale (GSE) (Schwartzer & Jerusalem, 1995)
Self Regulation	4	Self Regulated Learning (Pintrinch & De Groot, 1990)
Metacognition	8	Self Regulated Learning (Pintrinch & De Groot,1990]

Table 2 – Survey Subscales.

Koh, et al. (2010) found that the participants perceived their psychological needs to be satisfied, and showed high self-determined motivation. The results in Table 3 suggest that the participants in both the C and E Groups perceived their psychological needs to be

satisfied, with the C group experiencing highest satisfaction in autonomy support, and the E group in competence. See table 3 below.

Subscale	Experimental		Control		Cronbach's
	Mean	Std. Deviation	Mean	Std. Deviation	Alpha
Autonomy Support*	3.583	0.648	3.849	0.46153	0.762
Competence	3.820	0.636	3.742	0.72189	0.857
Relatedness	3.580	0.714	3.503	0.80575	0.778
Amotivation	2.218	0.816	2.333	0.85352	0.754
External Regulation	2.544	0.992	2.711	0.90132	0.596
Introjected Regulation	2.399	0.910	2.211	0.84267	0.728
Identified Regulation	4.029	0.606	4.044	0.57970	0.734
Intrinsic Motivation	3.733	0.688	3.876	0.80373	0.828
Self Efficacy	3.780	0.571	3.674	0.55392	0.755
Self Regulation	3.417	0.705	3.261	0.63950	0.748
Metacognition	3.622	0.607	3.674	0.44084	0.794

* Denotes significant differences at the 5% (.05) level between Control and Experimental groups

Table 3 – Descriptive Statistics and Alpha Coefficients.

For both groups, the lowest perceived satisfaction was in relatedness. These findings differ from those in an earlier study on polytechnic engineering students, whereby the researchers observed highest satisfaction for relatedness, and at decreasing levels, competence and autonomy support (Liu & Chye, 2008). One could suggest that the teaching and learning environment in the current study contributed, at least in part, to high perceived needs satisfaction amongst the students (both C and E groups), and that students who experienced SBL (Experimental group) perceived higher competence than their peers in the C group. However, the E group expressed significantly lower satisfaction in autonomy support than the C group – this may be due to the fact that some of the students might have felt a lowered sense of autonomy when their suggestions on how to improve the SBL process were not accepted by the course instructors on account of the need to adhere to safety protocols. Secondly, autonomy support is more about the SBL context rather the program per se. As such, although SBL was designed to give students greater choice in terms of when and how often they intended to use it, the students might have felt that the program was imposed on them since the half-hour SBL component was mandatory for the E group. Furthermore, although the "Explore" simulations allowed the students some freedom to interact with the various components of the machines, the "Practice" simulations, once launched, prompted the users to follow a controlled sequence of procedures, with few opportunities for the students to devise their own course of action. Also, the inclusion of SBL might have introduced time constraints that limited students' opportunities to conduct further explorations on the topic in ways that they deemed appropriate, hence their perception of low autonomy support.

The comparatively lower perceived relatedness amongst students suggests that further improvements could be made to the current system, in terms of promoting students' interaction and communication during lessons. Conventional teaching in engineering tends to adopt a didactic approach, while in SBL, students tend to focus their attention on the computer simulations, rather than engage in discussions with their peers. Course tutors should consider including collaborative strategies, such as the use of computer-mediated

communication and computer-supported cooperative work in the SBL program to enhance students' engagement. Engineering faculty can also consider using the wide range of Web-based discussion and networking platforms, such as wikis and blogs, to encourage collaboration and engagement amongst students. Nevertheless, relatedness is best fostered through face-to-face contact, and schools should provide opportunities within and outside curriculum time, for social interaction and community building.

In terms of motivation, both the C and E groups had high mean scores for identified regulation and intrinsic motivation, the more self-determined forms of motivation. This indicates that these engineering students valued the importance of their course, most likely for the acquisition of skills required for their future employment. The fact that most of them would have taken up engineering out of their own choice explains their interest, hence intrinsic motivation in the course. It is thus not surprising that both the E and C groups showed high perceived self-efficacy and metacognition. However, whereas the E group had high self-regulation, the C group obtained lower mean scores than their counterparts in the E group, suggesting that although both groups had confidence in their ability to meet the demands of the course, SBL might have inculcated greater self-regulation amongst the students in the E group. Nevertheless, other than significant differences in mean scores for autonomy support, further analysis of the data using the t-test showed that the differences in mean scores between the E and C groups were not significant. This could be accounted for by a number of factors, including the limited sample size, and the relatively short exposure time to SBL, which could have been inadequate, in this particular context, to produce significant effects on motivation.

4.2 Learning (Level 2)

Evidence for learning was collected through an interview and summative tests involving only the SBL participants and a formative test involving selected participants from control and experimental groups. There is a strong indication that much learning took place. A qualitative study involving 18 Singaporean participants revealed the value of SBL for learning (Fang, Tan, Thwin, Tan & Koh, 2011). In their interview, SBL participants highlighted that the SBL lessons helped them be familiar with the conventional machines before workshop practice. SBL also made a deep impression on the participants' visual experience, helping them remember the machine processes.

The SBL teaching materials were designed to help participants learn the following: parts of the machine from text descriptions (Know the Machine), how the parts worked by clicking on higlighted handles or buttons (Explore the Machine) and learn the steps required to perform a task through voice and text instruction (Work on the Machine-Lessons). The participants were expected to show that they had learnt the steps on their own (Work on the Machine-Test). The results of their summative online tests held in weeks two, four and six, conducted just before workshop practice showed that they were mastering the steps of the procedures for milling, drilling and sheet metal (Fang, et al., 2011). See Table 4 for the scores of the formative test collected just before the SBL participants proceeded for their workshop practice. Eight participants with GCE "O" levels had a more academic background compared to the 10 with qualifications from the Insitute of Technical education.

Machine Process	Number of steps tested	Maximum Achievable Score	Participants	Average score *	Average number of errors
Turning	14	70 (100%)	All	67.1 (95.8 %)	3
			ITE	67.2 (96 %)	3
			GCE O	66.9 (95.6 %)	3
Sheet Metal	9	45 (100%)	All	43.6 (96.8 %)	1
			ITE	42.7(94.9 %)	2
			GCE O	44.6 (99.1 %)	0
Milling	12	60 (100%)	All	55.8 (92.9 %)	4
			ITE	54.4 (90.7 %)	6
			GCE O*	57.7 (96.2 %)	2

Table 4 – Formative test scores for Milling, Sheet Metal & Turning.

SBL was able to match the learning needs of the 18 Singaporean SBL participants as they came from different backgrounds. Those with GCE "O" levels worked on the materials more. In general, those with more technical background reported that they used SBL more selectively and for test preparation while those with GCE "O" levels used it more for learning (Fang, et al., 2009). See table 5 for usage by the different groups of participants.

Participants' Usage of Levels	**Know, Explore & Work (Lessons & Test)**	**Explore & Work (Lessons & Test)**	**Work (Lessons & Test)**	**Work (Test only)**	**Total**
All	39% (7)	22% (4)	33% (6)	6% (1)	100% (18)
ITE	30% (3)	20% (2)	40% (4)	10% (1)	100% (10)
GCE	50% (4)	25% (2)	25% (2)	0% (0)	100% (8)

NB: The percentages were rounded to whole numbers

Table 5 – Levels Used by Educational Qualifications.

The research team also looked at learning from the summative learning based on a post-intervention test conducted in week seven. The pen-and-paper test required participants in the C and E groups to apply and synthesise their knowledge on machining operations. Participants were to plan to produce a common part that required machining processes from different workshop machines. Answers could be in words, a sketch, flow chart, table or a combination of these.

The C Group consisting of 45 participants and E Group, consisting of 69 participants were those who were taking Machining Technology for the first time. The participants from both the E and C Groups formed three sub-categories based on their different educational backgrounds. In the E Group, 38% were international students who were schooled in their homeland before coming to Temasek Polytechnic, 15% were Singaporeans who had more academic training and had GCE-O levels while 47% were Singaporeans who had qualifications from the Institute of Technical Education. In the C Group, 24% were international students, 7% were Singaporeans with GCE-O levels and 69% were Singaporeans with ITE qualifications.

Results of 113 participants (45 from C Group and 68 from E Group, 1 absent) were analysed. 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, $t(111)=1.996$, $p<.05$, (two-tailed). The effect size at .384 can

be considered a medium value given that only 30 minutes of a 2-hour session was given to using SBL. The interquartile range for the C Group was larger (4.0), indicating that of the E Group (2.0) had less variation in the understanding of the topic (Tan, et al., 2009). The theoretical pen and paper test indicated that participants using SBL benefit in terms of connecting concept and knowledge retention. Koh, et al. (2010) also found that while those who had the benefit of SBL obtained higher mean test scores, factors such as gender, educational backgrounds and IT competencies seemed to influence the outcomes.

4.3. Transfer of Learning (Level 3)

The research team attempted to look for evidence of transfer of SBL during workshop practice (Fang, Thwin, et al., 2010). This involved workshop observations of SBL and non-SBL participants working in teams. The observation, conducted by a domain expert, was based on the Workshop Observation Toolkit for Groups which he had designed for this study. The checklist included items on familiarity with the workshop tasks, responsiveness to workshop instructor's questions, ease in teaching the participants, ability to work independently and pace of work. This was followed by interviews with the workshop instructors.

The study by Fang, Thwin, et al. (2010) focused involved comparing workshop teams from the E and G groups. Two involved with only Singaporeans and while two comprised an equal mixture of Singaporeans and international students. The groups had about the same skill set. The positive effects of SBL varied from strong to marginal. It showed that the 16 SBL participants seemed more prepared for workshop practice than their 18 non-SBL counterparts. Many were able to visualize machine parts, worked faster and were easier to teach for Sheet Metal.

Generally, the international students in the work teams for this study needed processes to be repeated. Perhaps it was their lower ability to process information in English. Kwok, et al. (2009) and Tan, et al. (2010) found that when an SBL group comprising 75% international students from the same asian country were added to the comparison matix, the transfer of learning was least apparant. This was because they were was not too receptive to SBL.

5. Discussion

Despite the limitations in comparing studies which focused on different groups and the varying research methodolgies, the results and findings from the various studies were able fit well under the three levels of learning. Despite the different sizes of the studies, a common theme points to learner differences. The Singaporean students were more receptive to SBL than the international students, benefited more for learning and were able to transfer their learning better. These could because of prior educational experiences and background as well as competence in English. SBL did facilitate learning at the formative and summative stages. The transfer of learning was more apparant for Singaporean participants than international students.

6. Conclusion

The use of the Kirkpatrick (1994) Learning Evaluation Model to review results and findings from existing studies has provided the research team different facets of the effectiveness of SBL in a systematic manner.

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