The Effects of Simulation-based Learning on Engineering Workshop Practice

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ABSTRACT

This qualitative study on the effects of Simulation-based learning (SBL) on Machining Technology workshop practice involved two workshop groups that had SBL infused into their curriculum and two workshop groups that received normal instruction. The research question was "How did SBL help to prepare participants for workshop practice?" The sub-questions were as follows:

i. Were the SBL workshop groups more familiar with the workshop tasks?
ii. Were they more responsive to their instructor's questions?
iii. Were they able to work more independently?
iv. Were they able to work faster?
v. Were they easier to teach?

Each workshop group was observed thrice. In addition to the data collected using the Practice Observation Toolkit for Groups, there were observation notes and staff interviews. Personal data of 16 SBL and 18 non-SBL participants, usage of SBL modules and written comments from the SBL participants were also collected. While the SBL participants seemed more prepared for workshop practice, were able to visualize machine parts, worked faster and were easier to teach, the positive effects of SBL varied from strong to marginal.

Keywords: Positive effects of Simulation-based learning, transfer of learning, Engineering workshop practice

INTRODUCTION

Educational simulations provide "a variety of selectively interactive, selectively representational environments that can provide highly effective learning experiences" [1, p. 270]. Computer simulations can help students understand and visualize theoretical problems, allowing them to practice, be assessed and measured for understanding of the theory and application [2]. Effective learning requires transfer, where current learning is applied or adapted to similar or novel situations [3]. It is assumed that when learners are able to perform a task in a simulated environment, they would eventually assimilate the necessary skills and concepts over time [4]. Simulation-based e-learning is supposed to help learners move seamlessly from learning-by-doing to improved real job performance [5]. However, there could be a gap between the simulator and operational performance [6] or the real-world performance cannot be fully reflected [7].

There have been studies on the transfer performance of different target groups in a simulation of a chemical plant [8], the transfer of spatial knowledge in virtual environment training [9], the application of knowledge in flexible situations [10], and the performance of medical students in practical tests [11]. However, there are no studies that look at transfer in Machining Technology workshop practice.

Temasek Engineering School explored the use of SBL in the 2008 for Machining Technology, a subject taken by year two semester one Mechatronics students. During the October 2008 semester, three out of five classes in the cohort had SBL infused in their curriculum. It was hoped that SBL could support learning in the classroom and prepare students for workshop practice. See Figure 1 for the conceptual framework.

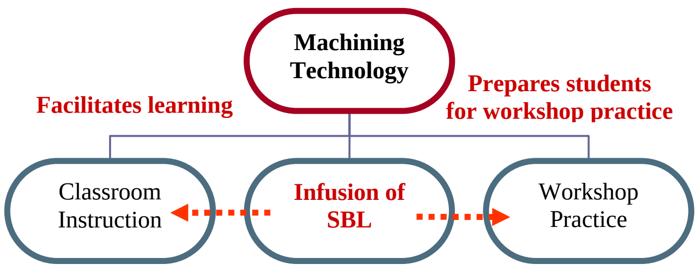

Figure 1. Conceptual Framework for the Infusion of SBL

The research question was "How did SBL help to prepare participants for workshop practice?" The sub-questions were as follows:

i. Were the SBL workshop groups more familiar with the workshop tasks?
ii. Were they more responsive to their instructor's questions?
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This study was part of a larger study on the effectiveness of SBL for Machining Technology. It was designed to complement the study on the effects of SBL during workshop practice at the individual level.

LITERATURE REVIEW

Computer-based technical training can be designed to teach facts, concepts, processes and procedures and principles to facilitate memory and application of lessons [12]. The virtual environment has much potential for learning [13] and training [14]. Virtual products and virtual laboratories have been used extensively in the teaching of Engineering [15-19]. Virtual products can be offered on a stand alone basis or embedded in virtual laboratories. While virtual products allow users be familiar with new products when they “interact with visual, selectively accurate representations of actual products without the physical restrictions of reality” [1, p. 5], virtual laboratories present situations where products are actually used, however at the expense of fidelity [1].

The effectiveness of SBL has been evaluated in different way, for instance, by comparing effect size of experimental and control groups [20], relating time spent on SBL to the achievement of standardized learning outcomes [21], contrasting pre-test and post-test scores [10], comparing initial and final assessment checklist scores [11], and evaluating performance in set tasks [9].

Transfer of learning has multiple definitions and interpretations. According to Eddy and Tannenbaum [22, p. 164] cognitive psychologists consider transfer as the “application of learning from a learned task to a different task “ while instructional designers consider it as “the application of learning in situations different from where learning took place”. Leberman, McDonald and Doyle [23] attribute the differences to the learning approaches, whether it is formal discipline, behavioral, cognitive and allied or contextual socio-cultural approaches. Haskell [3] categorized transfer at six different levels: simple learning i.e. non-specific and application transfer (levels one and two); application of learning i.e. context transfer (level three); near transfer (level four); and far transfer i.e. far and creative transfer (levels five and six respectively). He also identified 14 different kinds of transfer e.g. content-to-content transfer, procedural-to-procedural transfer, declarative-to procedural transfer, procedural-to-declarative transfer, strategic transfer, conditional transfer, theoretical transfer, general or nonspecific transfer, literal transfer, vertical transfer, lateral transfer, reverse transfer, proportional transfer and relational transfer. Transfer is considered positive when “learning in one context improves learning or performance in another context” [23, p. 4].

Temasek Polytechnic’s Strategic and Quality Development Department [24] learning outcomes for the cognitive domain are based on Bloom’s Taxonomy [25], which are knowledge, comprehension, application of concepts and principles to new situations, analysis and synthesis and evaluation. For the psychomotor domain, learning outcomes are based on Simpson’s classification [26], which are perception, set, guided response, mechanism, complex overt response, adaptation and origination. Machining Technology students are expected to demonstrate their understanding of the different applications of the types of conventional machines, the machine parameters, and the different work holding devices as well as operate them [27]. A written post-intervention test had showed that SBL helped improve higher-order learning, demonstrating transfer in the cognitive domain [28, 29].

METHODOLOGY

Machining Technology subject was taught in a four hour blocks weekly. Two hours of classroom instruction followed two hours of workshop practice, which were fully guided. The first seven weeks were designed to help students use conventional machine and basic bench-fitting tooling for assembly work. The activities supported two individual projects which were the fabrication of a pen holder and a metal box. The former required turning, milling, drilling while the latter involved shearing, bending, drilling and bench work for sheet metal. The SBL lessons were designed as virtual objects and packaged as one project and four teaching modules. The teaching modules, namely Turning, Sheet Metal, Milling and Drilling offered different levels of learning. *Know the Machine* provided an introduction to the machine parts and functions, and a short MCQ online quiz to help students evaluate how much they had learnt. *Explore the Machine* provided a preview of how each machine works, while *Work on the Machine* provided guided practice on a virtual machine followed by a simulation test which required students to repeat the procedure without any guidance. The Project Work module demonstrated the use of a combination of different machines to support the two projects.

SBL was used in class. The Machining Technology tutor introduced the SBL materials though the use of the Drilling module in week one. Students were allocated 30 minutes just before their workshop practice and learnt from the Turning, Sheet Metal and Milling modules as each process was introduced in weeks two, four and six respectively. They were also encouraged to access the SBL materials outside class time.

The study involved four randomly selected workshop groups from two SBL and two non-SBL classes. There were sufficient similarities in group composition for comparison between the SBL and non-SBL workshop groups despite the variation in nationalities and educational backgrounds. The workshop group size ranged from eight to 10 participants. The ratio of participants with qualifications from the Institute of Technical Education (ITE) to those with General Certificate of Education (GCE) “O“ level qualifications was similar for the Singaporean SBL and non-SBL workshop groups. The mixed SBL and non-SBL workshop groups had the same number of Singaporeans and international students, and a similar ratio of participants with ITE to GCE “O“level qualifications. Those with ITE and GCE “O” level qualifications were Singaporeans, while those with international qualifications were international students and one Singaporean who completed his GCE “O” levels at an international school in Malaysia. See Table 1.

Table 1: Details of SBL and non-SBL Workshop Groups

Entry Qualifications	Number	Ave Age	Ave GPA	Ave Login
SBL Singaporean Workshop Gp	**8**	**22.6**	**2.76**	**85.9**
- ITE	6	22.5	2.55	92.8
- GCE “O”	2	23.0	3.41	65.0
SBL Mixed Workshop Gp	**8**	**19.4**	**3.16**	**103.5**
- ITE	3	19.8	2.75	74.0
- GCE “O”	3	19.7	3.20	105.7
- International	2	18.6	3.71	144.5
Both SBL Workshop Groups	**16**	**21**	**2.96**	**94.7**
Non-SBL Singaporean Workshop Gp	**10**	**21.4**	**2.91**	
- ITE	7	22.0	2.81	
- GCE “O”	2	21.0	2.84	
- International	1	18.0	3.77	
Non-SBL Mixed Workshop Gp	**8**	**22.1**	**2.76**	
- ITE	4	23.0	2.71	

- GCE "O"	2	18.7	2.49
- International	2	23.8	3.13
Both Non-SBL Workshop Gps	**18**	**21.7**	**2.84**

Their technical training backgrounds prior to joining Temasek Polytechnic ranged widely. Those with international qualifications had an academic background and none or hardly any technical training. Those with GCE "O" level qualifications had an academic background with varying exposure to Design Technology. Those with ITE Electrical-IT qualifications had practice-based training not related to Machining Technology. Those with ITE Mechanical qualifications had practice-based training related to machining technology. See Chart 1.

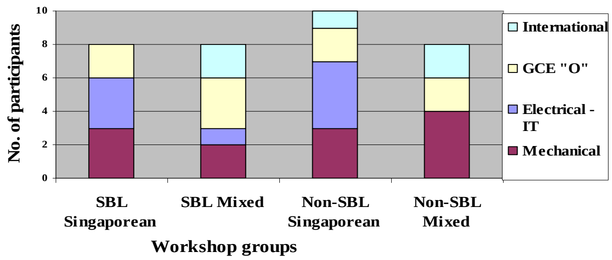

Chart 1. Profile of workshop groups

As workshop practice was fully guided, the workshop instructor would demonstrate the use of the machines before allowing participants to work on individual machines. To ensure that the method of instruction was consistent, the two instructors were briefed on the instructional materials, key points of the demonstration, the types of questions to ask and what to observe during the session.

Each group was observed for their Turning, Sheet Metal and Milling workshop practice sessions in weeks two, four and six respectively. All observations sessions were video-taped. At the beginning of each session, the participants were reassured that that the data recording of the observation session had no bearings on their workshop practice grades.

The first instrument used was the Practice Observation Toolkit for Groups, which was specially designed by a domain expert. He first analyzed the course book and teaching notes, observed several workshop practice sessions and had extensive discussions with the workshop instructors before developing the workshop practice learning model that focused on interactivity, work pace and independence (see Figure 2).

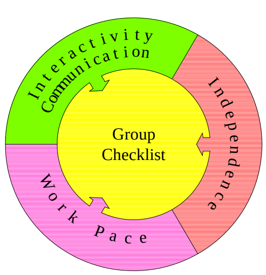

Figure 2. Model of Workshop Practice

He then identified 11 items that could possibly capture, identify or reflect the effects of SBL as the workshop progressed and categorized them as follows:

i. *Familiarity with workshop tasks*: engages in discussion on topics related to workshop practice; checks with instructor and peers
ii. *Responsiveness to instructor*: responds to instructor's questions
iii. *Ability to work independently*: works independently; checks with instruction sheet; seeks assistance from peers and relies on them for help; clarifies repeatedly with instructor
iv. *Pace of Work*: completes all tasks ahead of schedule, within or beyond schedule.

These indicators formed the basis of the form for the Practice Observation Toolkit for Groups. Data was collated by occurrences. The workshop instructors and domain expert also took observation notes.

The second instrument was an unstructured, open-ended interview for staff. It focused on the behavior of the participants in the workshop and whether they easier to teach. The domain expert and his assistant were interviewed together on Dec 3, 2008 for 30 minutes while the two workshop instructors were interviewed together on Dec 9, 2008 for about 45 minutes.

In addition, personal data, log in data, test scores and written comments from the participants were also collected. These were used to build a profile of each workshop group.

The observation forms and notes were saved in Microsoft 2003 Excel and Word files respectively while the interviews were transcribed and stored in Microsoft 2003 Word files. The observation data were compared against the observer's notes, interview transcripts, participant's personal data, their comments, SBL logins and test scores.

FINDINGS

The number of log-ins to the SBL modules in Table 1 indicated that the SBL participants were using SBL. In addition, 87.5% of the SBL participants wrote that SBL had prepared them in terms of what to expect in the workshop, and had helped them understand the parts of the machine and learn how to operate the machines. The data presented was based on the summation of the participants observed over three sessions taking into account the absentees: 22 for the SBL Singaporean workshop group (two absentees), 23 for the SBL mixed workshop group (one absentee), 30 for the non- SBL Singaporean workshop group, and 21 for the non-SBL mixed workshop group (three absentees).

Familiarity with Workshop Tasks

Indicators on how well SBL prepared participants for their workshop practice were as follows: the need to discuss workshop practice matters and check with their instructor and workshop group members. Table 2 shows the average percentages for their need to discuss workshop-related matters.

Table 2. Need for Discussion

Workshop groups	Discussed workshop matters	Checked with Instructor	Checked with Peers
Both SBL	**80.0%**	**22.2 %**	**22%**
SBL Singaporean	77.3%	18.2%	9.1%
SBL Mixed	82.6%	26.1%	34.8%

Both Non-SBL	**92.6%**	**10.5 %**	**46.4%**
Non-SBL Singaporean	90.0%	6.7%	50.0%
Non-SBL Mixed	95.2%	14.3%	42.9%

The SBL workshop groups needed to communicate less (80.0%) than the non-SBL workshop groups (92.6%) about workshop matters. The non-SBL workshop groups were most actively involved in discussion, and seemed more interactive and lively particularly during the demonstration sessions. The SBL workshop groups communicated more often with their instructor (22.2%) than the non-SBL workshop groups (10.5%). The non-SBL workshop groups communicated twice as often (46.4%) with their group members compared to the SBL workshop groups (22%). They often asked for extra information and clarification and communicated more with their peers (46.4%) than the instructor (10.5%).

The workshop instructors noticed that as the international students generally mingled well with Singaporeans in their group, they would clarify their doubts with them. If the Singaporeans had doubts, they would ask their instructor. Perhaps that might have been the reason for SBL mixed workshop group's high "checking with instructor percentage" (26.1%) and a relative high "checking with peers" percentage (34.8%).

Responsiveness to Workshop Instructor

The second indicator of preparedness for workshop practice was the participants' responsiveness to the workshop instructor's questions. Table 3 shows the response rates by workshop groups.

Table 3. Responsiveness to Instructor's Questions

Workshop Groups	Responded to Instructor's Questions
Both SBL	**35.4%**
SBL Singaporean	27.3%
SBL Mixed	43.5%
Both Non-SBL	**61%**
Non-SBL Singaporean	60.0%
Non-SBL Mixed	61.9%

On average, the SBL groups responded less to the instructor's questions compared to the non-SBL groups. However, the instructors noticed that some SBL participants were able to visualize machine parts and provide correct answers. Both SBL and non-SBL workshop groups were able to answer the instructor's questions correctly.

Ability to Work Independently

Independence was determined by the following: the ability to work independently, the need to refer to the instruction sheet, the level of dependence on workshop group peers to explain and assist and the need to clarify with the instructor. See Table 4.

Table 4. Level of Independence

Workshop Groups	Worked Independently	Required Instruction sheet	Depended on peers	Clarified repeatedly with instructor
Both SBL	**42.3%**	**62.2%**	**11.3%**	**6.7%**
SBL Singaporean	45.5%	59.1%	18.2%	9.1%
SBL Mixed	39.1%	65.2%	4.3%	4.3 %
Both Non-SBL	**39.0%**	**72.6%**	**12.1%**	**8.1%**
Non-SBL Singaporean	40.0%	83.3%	10.0%	6.7%
Non-SBL Mixed	38.1%	61.9%	14.3%	9.5%

The workshop instructors noticed that the SBL workshop group preferred individual work, the non-SBL mixed group preferred working with each other while those in the non-SBL Singaporean workshop group sometimes preferred to work as group and at other times, individually.

Generally, the SBL workshop groups were more task-oriented and were more independent (42.3%) compared to the non-SBL workshop groups (39%) who tended to move around, talk and discuss while working on the machines. The SBL Singaporean workshop group was the most independent (45.5%). The SBL mixed group was marginally more independent (39.1%) than the non-SBL mixed workshop group (38.1%) but marginally less independent than the non-SBL Singaporean workshop group (40%).

In general, the non-SBL workshop groups looked at the instruction sheet more often (72.6%). However there was no specific pattern as to which comparative pair of workshop groups looked more at the instruction sheets. The SBL Singaporean workshop group looked at the workshop instruction least (59.1%) while the non-SBL Singaporean workshop group looked at it the most (83.3%) However, the SBL mixed workshop group needed to look at the instruction more (65.2%) than the non-SBL mixed group (61.9%).

The SBL workshop groups depended less on their peers for help (11.3%) compared to the non-SBL workshop groups (12.1%), However, the SBL Singaporean workshop group depended more on their peers for help (18.2%) compared to the non-SBL Singaporean workshop group who required the least assistance from their peers (10%). The SBL mixed group required the least help (4.3%) compared to the non-SBL mixed workshop group (14.3%).

The SBL groups seemed to need less repeated clarification (6.7%) with the instructor than the non-SBL groups (8.1%). However, the SBL Singaporean workshop group referred more to the instruction (9.1%) than their non-SBL Singaporean counterparts (6.7%). The SBL mixed workshop group required the least clarification (4.3%) while the non-SBL mixed workshop groups required the most (9.5%).

Pace of Work

The working pace differed among the workshop groups. The instructors felt that the SBL Singaporean workshop group was the best in terms of overall performance followed by the SBL mixed group, the non-SBL Singaporean group and finally the non-SBL mixed group. Table 5 shows the average completion rate for each workshop group and the overall average for the SBL and non-SBL workshop groups.

Table 5. Completion rate for workshop tasks

Workshop Group	Ahead of schedule	Within schedule	Behind schedule
Both SBL	**26.8%**	**73.3%**	**0%**
SBL Singaporean	31.8%	68.2%	0.0%
SBL Mixed	21.7%	78.3 %	0.0%
Non-SBL	**20.3%**	**60.7%**	**19.1%**
Non-SBL Singaporean	16.7%	50.0%	33.3%
Non-SBL Mixed	23.8%	71.4%	4.8%

The overall work pace of the SBL groups was generally faster than that of the non-SBL groups. For the "completion ahead of schedule" sub-category, the SBL groups were faster (26.8%) than the non-SBL workshop (20.3%). The SBL Singaporean workshop group was the fastest (31.8%) of all the groups. The non-SBL mixed workshop group (comprising 50% or four participants from the ITE with Mechanical training) was marginally faster than the SBL mixed group (comprising 25% or two participants from ITE with Mechanical training).

For the "completion within schedule" sub-category, the SBL workshop groups were generally faster (73.3%) than their non-SBL counterparts (60.7%). However, the SBL Singaporean workshop group had a higher completion within schedule rate (68.2%) compared the non-SBL Singaporean workshop group (50%). The SBL mixed group had the highest "completion within schedule" rate (78.3%) followed by the non-SBL mixed group (71.4%).

For the "completion behind schedule" sub-category, 19.1% from the non-SBL workshop groups could not complete their work within schedule; 33.3% from the non-SBL Singaporean workshop group and 4.8% from the non-SBL mixed group.

Easy to teach

Generally, the four workshop groups were easy to teach. However, the SBL groups were easier to teach for Sheet Metal in week four. The workshop instructors noticed that all international students needed processes to be repeated.

DISCUSSION

The effects of SBL on workshop practice were derived by comparing the SBL and non-SBL workshop groups using a scale ranging from large, moderate, marginal, neutral and negative. The positive effects of near transfer [3, 23] of SBL ranged from large to marginal.

Large Positive Effect

It could be inferred that SBL helped to familiarize participants with workshop practice tasks as there was comparatively less need to discuss matters related to workshop practice. The SBL workshop groups were more task-orientated, and referred more to the instructors than the non-SBL workshop groups. This could be the result of their transferring their knowledge and comprehension of concepts from the SBL lessons [25] to the workshop environment. It also achieved the instructional objectives of psychomotor domain for perception (awareness) and set (mental readiness to act) [26]. The need of the non-SBL groups to discuss workshop matters could have been a strategy that they used to compensate for the lack of SBL instruction, and mainly looked to their peers to make sense of their learning tasks.

Large -Moderate Positive Effect

SBL seemed to provide an advantage in terms of work pace involving performance of a complex motor skill [26]. This could have involved procedure-to-procedure transfer [3]. Overall, the SBL Singaporean workshop group performed better than their non-SBL Singaporean workshop group. The SBL mixed group was somewhat better than the non-SBL mixed group. The mixed non-SBL group, with twice the number of ITE participants, completed their tasks ahead of time; however a number could not complete their work on time. The transfer of learning helped the SBL group achieve the objectives in the guided, mechanism and complex overt response categories of the psychomotor domain [26].

Moderate Positive Effect

The SBL groups were noticeably easier to teach for Sheet Metal (week 4) where there was certainly procedure-to-procedure transfer [3]. The SBL workshop groups were able to visualize the machine parts, perhaps through the transfer of their visual memory of the machine parts [25] to the workshop environment, meeting the perception category in the psychomotor domain [26].

Marginal Positive Effect

The SBL groups were marginally more independent, less reliant on the instruction sheet, their peers and instructor. The SBL mixed group seemed to rely more on their instruction sheet and less on their peers and instructor compared to the SBL Singaporean group. Perhaps the SBL preparation helped familiarize them with the sequence. This helped achieve the perception and set categories for the psychomotor domain [26].

The non-SBL group referred more to the instruction sheets, and perhaps because they had discussed more with each other initially, they might not have needed so much assistance from their peers.

CONCLUSION

There were positive effects of SBL on workshop practice, although varied. The findings suggest that the effect was large for all SBL groups in the area of workshop preparation, reducing the need to discuss with their peers. SBL had a large to medium effect in terms of work pace. It was moderate in terms responsiveness, in their ability to visualize the machine parts, ease in teaching them, and marginal in terms of independence. As transfer of learning appears in different guises, further work is required. Interviewing groups immediately after each workshop practice would verify the findings and help enhance the understanding of transfer in workshop practice.

Acknowledgements

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