Investigating the Effect of 3D Simulation-Based Learning on the Motivation and Performance of Engineering Students

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BACKGROUND
Simulation-based Learning (SBL) was used in Machining Technology, a sixty-hour module for second year engineering students, at the School of Engineering at Temasek Polytechnic. The aim of this study was to investigate the effect of SBL on learners' motivation and performance. In assessing students' motivation, we adopted a framework based on the Self-determination Theory (SDT), chosen on account of its comprehensive treatment of the relationship between students' perceived needs satisfaction and their motivation.

PURPOSE (HYPOTHESIS)
It is hypothesized that SBL, which provides learners with interactive learning experiences, will enhance students' motivation and performance. We explored the effect of SBL on students' perceived psychological needs satisfaction, motivation, and learning, and how SBL affected students' understanding and application of content knowledge.

DESIGN/METHOD
The intervention procedure involved the incorporation of SBL in Machining Technology, a 60 hour module in the mechanical engineering program. Survey findings and post-intervention assessment outcomes were used to assess the students' perceptions of their basic psychological needs satisfaction, motivation, and performance.

RESULTS
Our findings suggest that the students perceived their psychological needs to be satisfied and had high levels of self-determined motivation. Students who undertook SBL had higher mean performance test scores, although SBL may have differential effects on learners depending on factors such as gender, educational backgrounds, and IT knowledge.

CONCLUSIONS
Our findings suggest that the students perceived their basic psychological needs to be met and that SBL can potentially enhance self-determined motivation as well as improve learning in general.

KEYWORDS
simulation-based learning, motivation, self-determination theory

I. INTRODUCTION

Recent advances in technology have introduced new tools to enhance learning, especially in higher education. Among these, computer simulations have been used in a wide range of contexts, such as in supporting differentiated learning (customizing learning for students of diverse abilities), collaborative learning (learning in groups), and skill needs learning (learning for skills mastery) (de Freitas, 2006). Setting up virtual laboratories via interactive 3-D simulation is one way of augmenting the learning and training processes with substantial benefits. For example, it promotes self-directed learning activity, improved motivation, learner engagement, natural semantics, safe space, and cost savings. The simulation system has the advantage of closely replicating the original physical milieu, thus providing opportunities to investigate situations hitherto deemed difficult or impractical to explore in actual settings (Tan, 2008). The use of computer simulation to enhance learning has been well studied in engineering education and other fields, with abundant literature reporting its effectiveness in improving students' conceptual understanding and learning process. Thus, simulations have been used in a wide variety of teaching and learning contexts, such as improving cognitive achievement in agricultural mechanics (Agnew and Shin, 1990), project management in systems engineering (Davidovitch, Shtub, and Parush, 2007), fluid mechanics (Fraser et al., 2007), the development of Web-based interactive learning resources in engineering education (Ndahi et al., 2007), interactive digital media (Tan, 2008), and virtual laboratories (Balamuralithara and Woods, 2009). Outside the realm of engineering, simulations have been widely used in science education (Carlsen and Andre, 1992; de Jong and van Joolingen, 1998; Rieber, 1990) and the transfer of mathematical concepts (Reed, 1985; Lane and Tang, 2000). In medical and health care education, simulation methods have revolutionized training in areas such as critical care, surgery, and anesthesiology, enabling the transfer of knowledge and skills to health care providers, while ensuring patient safety (Abrahamson, Denson, and Wolf, 2004; Kneebone, 2003; Hammond, 2004; Ziv, Small, and Wolpe, 2000). Simulation-based learning also has a wide range of applications in military education and training, for example in the analysis of military problems and decision-making processes (Cioppa, Lucas, and Sanchez, 2004), in distance-learning military courses (Keh et al., 2008), and in flight simulator training (Hays et al., 1992).

However, whereas most of these studies focused on the enhancement of students' learning, there have been relatively fewer reports on systematic studies of the effect of computer simulations on students' motivation to learn. On the other hand, a rich source of well-documented research on motivation in education has been amassed since the 1930's (Weiner, 1990), but the impact of emerging technologies on students' motivation to learn still offers many avenues for exploration. In his address at the convention of the

American Educational Research Association, Weiner (1990, p. 621) suggested that future motivational research should focus not only on issues related to the self but on motivation involving "the development and the incorporation of the values of others." In this study, Self-determination Theory (SDT) was chosen as the underlying research framework due to the fact that this model takes into consideration behavioral regulations that are influenced by societal expectations. Furthermore, this study attempts to fill the gap in the existing literature on the use of Simulation-based Learning (SBL) to improve the performance *and* motivation of engineering students. We hypothesized that SBL would affect students' competence in the subject as well as promote autonomy in learning. SDT is thus appropriate for this investigation since it operates on the tenet that the level of autonomous, self-determined motivation increases with higher satisfaction of basic human needs, such as competence, autonomy, and relatedness.

This study investigates the use of SBL as an instructional strategy for improving learning and motivating students in a polytechnic engineering course in Singapore. In this country, formal education consists of a six-year elementary school program followed by four years of secondary schooling. At the end of their secondary education, most students sit for the University of Cambridge General Certificate of Education–O level (GCE-O) examinations. Students then have a variety of options to choose from when considering post-secondary education. Those with the necessary qualifications may choose to enroll in the junior colleges (offering academic courses) in preparation for university education, or in the polytechnics (offering applied, practice-oriented courses). Some of the less academically-inclined students spend an additional year in secondary school before taking up a vocational training course at the Institute of Technical Education (ITE).

On average, about 40 percent of the secondary school graduates opt to further their studies in the five polytechnics in Singapore (Chan, 2008). The polytechnics have a strong focus on practice-oriented learning, skills training, and on the preparation of their students for the future workforce. They also provide a unique setting for our study since the student population in the polytechnics is highly diverse, consisting of not only local Singaporean students but a relatively high proportion of foreign students from the neighboring Asian countries including Malaysia, Indonesia, Myanmar, Vietnam, India, and China. This enabled us to explore the impact of SBL on both local Singaporeans and an international pool of other Asian students. There is scant documentation on research conducted in the aforementioned fields in an Asian context, and as such, the findings of this study will assist in bridging the existing gaps.

A. Theoretical Framework

1) Basic Psychological Needs: We adopted a framework based on Self-determination Theory in our assessment of students' motivation. According to SDT, learner motivation is enhanced and becomes more self-determined when the three basic psychological needs for autonomy support, competence, and relatedness are satisfied (Ryan and Deci, 2000). Students perceive their needs for autonomy support to be satisfied when they are granted an optimal degree of volition and sufficient opportunities for choice in their learning (Deci and Ryan, 1985, 1987; Ryan, 1995). In a study on the motivational factors affecting students with learning disabilities and emotional handicaps, Deci et al. (1992) showed that autonomy support at home and at school promoted greater self-regulation, adjustment, and achievement. In the teaching of college-level chemistry, it was observed that instructors' support of autonomy led to increased students' perceived competence, greater autonomous motivation, and reduced anxiety (Black and Deci, 2000). A study on the emotional and academic consequences of parental conditional regard (Roth et al., 2009) showed that parental autonomy support predicted regulation of negative emotions, greater identification with the values of desired behaviors, and interest-focused engagement on the part of the children. Vansteenkiste, Lens, and Deci (2004, 2006) found that students' engagement in learning and their test performances improved when teachers provided an autonomy-supportive learning climate and made use of intrinsic goals (personal growth, health, relationships, and community) to frame learning activities.

Furthermore, studies showed that autonomy-supportive environments (providing the experience of volition and choice) promoted self-determined motivation which, in turn, led to higher perceived competence in the achievement of desirable outcomes and healthier behaviors (Williams and Deci, 1996, 2001; Williams, Freedman, and Deci, 1998; Williams et al., 2000). Likewise, the perception of self-competence was supported when students had adequate grasp of the taught subjects or skills, and when learning was followed by meaningful feedback from the course instructors. Research showed that students' self-efficacy (Bandura et al., 1996, p. 1206), improved with perceived competence and led to enhanced academic motivation and interest.

Finally, the need for relatedness is satisfied when students feel that they are accepted and valued by their peers and instructors within the learning environment. Researchers found that students attached greater value to a task and experienced a heightened sense of enjoyment when their contributions were valued by their peers and teachers and when they felt a sense of connectedness to the people in their learning milieu (Ryan, Stiller, and Lynch, 1994). Likewise, children attached more importance and showed greater personal commitment to school-related values when their parents provided more autonomy support and a greater sense of relatedness (Grolnick and Ryan, 1987).

Furthermore, when students perceive all three of their psychological needs to be satisfied, their motivation is likely to shift from a dependency on external regulation (punishment avoidance, rewards inclination or ego enhancement) to a more intrinsically directed orientation. The cross-cultural generalizability of SDT was shown in a study conducted in the collectivistic context of South Korea, whereby students perceived the most satisfying learning experiences in classroom environments supporting autonomy, relatedness, and competence (Jang et al., 2009).

2) Motivational Regulations: According to the tenets of SDT, three main levels of motivation can be distinguished: amotivation (the absence of motivation), extrinsic motivation (when a course of action is undertaken as a means to an end), and intrinsic motivation (when a course of action is undertaken for its own sake, out of interest or for enjoyment). Past research has focused predominantly on the attainment of intrinsic motivation, viewed as the main agent for effective learning and high attainment (Ryan and Deci, 2000). On the other hand, since extrinsic motivation centers on external goal orientations, it was perceived as providing a less noble intent for behavior and was thus translated as superficial and transient (deCharrms, 1968). However, in actual contexts, it is

rare to find students always intrinsically motivated in all aspects of learning and in all associated tasks and activities. For many students, the choice of a subject or field of study rests primarily on the instrumental value they attach to it rather than the enjoyment they derive from it. This led to the realization that, unlike intrinsic motivation which is essentially a one-dimensional construct, extrinsic motivation is multifaceted (Lepper, Corpus, and Iyengar, 2005) and, as SDT proposes, exists as a continuum of three increasingly self-determined behaviors (Deci and Ryan, 1985; Ryan and Deci, 2000). These are termed external regulation (most controlled), introjected regulation, and identified regulation (most autonomous). External regulation involves the control of behavior essentially by external means such as punishment, rewards, or higher authority. Introjected regulation describes behaviors arising from a need for ego enhancement or guilt avoidance, whereas identified regulation describes the behavior of an individual who makes autonomous choices based on sufficient importance or value being ascribed to them.

Many studies have shown that contextual support for the three innate psychological needs for autonomy, competence, and relatedness, leads to the enhancement of self-determined (autonomous) motivation (Deci et al., 1996). Figure 1 shows the effect of increased satisfaction of the needs for autonomy support, competence, and autonomy on enhancing the level of autonomous motivation.

In general, research has shown negative correlations between the three psychological needs and the state of amotivation (Koh et al., 2009; Liu et al., 2009; Ryan, 1995) suggesting that motivation is at its lowest when they perceive low levels of competence volitional expresssion, and sense of belonging. Correlations between the three psychological needs and the extrinsically motivated types of orientations showed a progression from negative or low correlates for external regulation to moderate positive correlations for identified regulation. On the other hand, perceived autonomy support, competence, and relatedness showed high positive correlations with intrinsic motivation, the most self-determined form of regulation. Furthermore, some researchers found that factors such as perceived relatedness and competence were effective in promoting self-determined motivation only when they were operating in tandem with a non-controlling, autonomy-supportive context (Fisher, 1978; Ryan, 1982; Usui, 1991). This suggests that the attainment of autonomous, self-determined motivation requires a complex interplay of factors leading to the satisfaction of the three basic psychological needs, primarily that of autonomy support. Table 1 shows the link between the three psychological needs and the motivational regulations within the self-determination continuum.

3) Associated Processes: Aside from motivation, this study investigated the effect of SBL on students' learning orientations, namely, the dispositions in learning such as self-efficacy, self-regulation, and metacognition. Although self-efficacy is closely associated with the psychological need for competence, we adopted Bandura's view of self-efficacy as people's "belief in their ability to exercise control over their level of functioning and environmental demands" (Bandura et al., 1996, p. 1206). Competence is perceived in the SDT framework as effectance (Deci and Ryan, 2000) or attainment of success and desired outcomes at optimally challenging tasks (Deci et al., 2001; Skinner, 1995; White, 1959). Metacognition, according to Schraw (1998), describes the knowledge of cognition (declarative, procedural, and conditional knowledge) and the regulation of cognition (processes involving planning, monitoring, and evaluating), and is often quipped as 'thinking about thinking.' Self-regulation is the process whereby a student uses metacognitive strategies to guide learning, manages and controls effort input, and employs cognitive strategies in learning, understanding, and remembering (Pintrich and De Groot, 1990). In addition, from the social cognitive perspective, self-regulated learning is thought to involve three processes: self-monitoring of activities, self-evaluation of performance, and response to feedback and

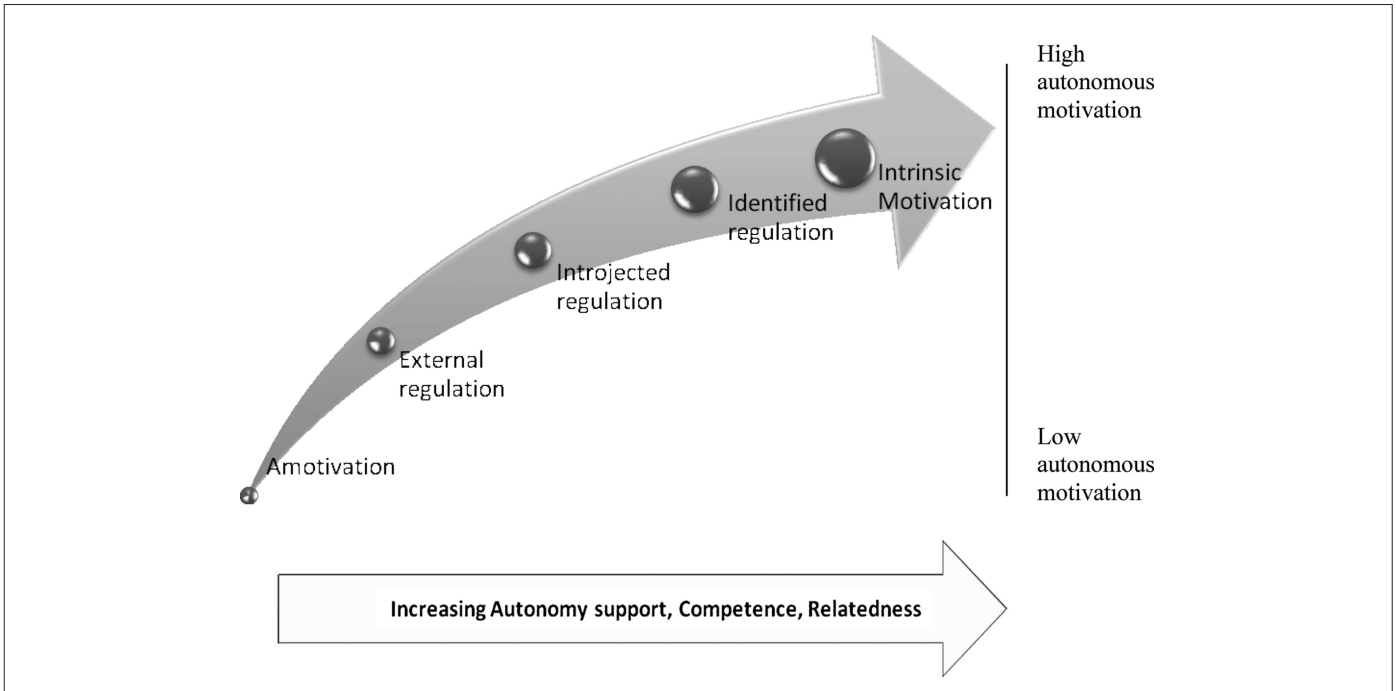

Figure 1. Increased self-determined motivation with enhanced psychological needs satisfaction.

		Basic Psychological Needs		
		Autonomy	**Relatedness**	**Competence**
Definition		Ability to experience volition and self-regulation	Development of secure and fulfilling interpersonal relationships within social environment	Effectance in task performance and attainment of outcomes
Examples		Students have the leeway to choose their own projects and their suggestions are acknowledged by others	Students are able to trust their peers and feel secure in their midst	Students succeed in optimally challenging tasks and are given positive feedback for their work
Motivational	Amotivation	−	−	−
	External	−	−	−/+
	Introjected	+	+	+
	Identified	+ +	+ +	+ +
	Intrinsic	+ + +	+ + +	+ + +

Table 1. Links between basic psychological needs and motivational regulations (− negative correlation; + low positive correlation; + + moderate correlation; + + + high correlation).

outcomes of performance (Zimmerman, 1990). We predicted that SBL would provide an interactive platform for higher engagement in students' learning and would promote the use of metacognitive processes through constant feedback given to the students as they progress through the SBL task. As a result of being more self-regulated in their learning, students would experience greater self-efficacy; that is to say, the belief in their ability to perform and complete a given task.

B. Research Questions

Our study explores the impact of SBL on engineering students' perceived psychological needs satisfaction, motivation, and their learning orientations. It attempts to answer the following research questions:

(1) To what extent were the basic psychological needs of polytechnic engineering students satisfied?
(2) To what extent did 3D Simulation-based Learning affect these students' perceived satisfaction of their psychological needs, their motivation, and learning orientation?
(3) How did 3D Simulation-based Learning affect these students' understanding and application of what they learned?

The uniqueness of our study lies in the application of a current, empirically well-supported motivational theory to empirical research in engineering education. Although the Self-determination Theory has been applied in a multitude of contexts including medicine (Williams and Deci, 1998), health care (Ryan et al., 2008; Sheldon, Williams, and Joiner, 2003), psychotherapy (Ryan and Deci, 2008), education (Deci et al., 1991), religion (Neyrinck et al., 2006), politics (Losier et al., 2001), and sports (Ryan and Deci, 2007), it has been sparsely explored in the domain of engineering. Our study attempts to build on the contributions of researchers in both motivation and engineering education, offering an Asian perspective to existing research. In addition, our findings will provide engineering educators with a heightened insight on the issues to be considered when implementing new teaching and learning approaches such as SBL.

II. Methodology

A. Participants

This study involved the participation of a total of 114 second-year engineering students from the School of Engineering in Temasek Polytechnic. The group consisted of 83 males and 31 females, with a mean age of 21 years. The students were randomly distributed in five classes, two of which were randomly assigned to the Control group (31 males and 14 females), and the other three classes to the Experimental group (52 males and 17 females).

The higher proportion of males as compared to females is a common feature in engineering courses (Anderson and Gilbride, 2007). The students from both the Experimental and Control groups formed three sub-categories based on their different educational backgrounds. In the Experimental group, for instance, 38 percent were international (foreign) students who were schooled in their homeland, 15 percent were local GCE-O level graduates from secondary schools, and 47 percent were local students from the ITE. In the Control group, the foreign students made up 24 percent, local GCE-O level graduates comprised 7 percent and local ITE students made up 69 percent. Analysis of students' performance in terms of their entry score to Year Two (Cumulative Grade Point Average, CGPA) showed that the Control and Experimental groups were equivalent in terms of their academic ability. Thus, a t-test based on students' mean CGPA showed no significant differences ($p = 0.17$) between the two groups with regards to academic ability. The students were randomly assigned to the five classes such that the mean CGPA of the classes were comparable, but this resulted in the distribution of the three sub-categories (international, ITE, and GCE-O) in the Control to be different from that in the Experimental group. Nevertheless, in investigating student motivation, it was important to distinguish between the three sub-categories as the culture and context of their former schooling may have profound implications on their perceptions of SBL as an instructional and learning strategy. For instance, course instructors observed that international students preferred to study with their fellow nationals and to use traditional learning methods. On the

other hand, ITE students favored a more practice-based approach to learning, while their GCE-O level counterparts were generally more academically inclined.

Both the Control and the Experimental groups had the same course curriculum, had their post-intervention quiz assessed by the same assessor, and were guided by the same group of instructors during workshop practice. However, due to constraints in teaching hours, two lecturers were assigned to teach the cohort. Thus, the first lecturer taught one of the classes in the Experimental group and the two classes in the Control. The second lecturer taught the two other Experimental groups.

B. Intervention Procedure

At the School of Engineering in Temasek Polytechnic, simulation-based learning has been used to improve students' motivation and learning in Machining Technology, a sixty-hour module for second year students of the Mechatronics (mechanical engineering) program. In this module, students are introduced to the features and functions of machines commonly used in mechanical engineering. The course requires visualization and manipulation of machine components as well as the understanding of machine systems and their variables. Course instructors often observed that students had difficulties recalling the functions of these machines and the specific use of their various components. It was hypothesized that computer simulations, which provide learners with first-hand, interactive learning experiences, would improve students' motivation and enhance their mastery of the required skills.

From the SDT perspective, it was predicted that computer simulations would increase students' perceived psychological needs satisfaction, leading to enhanced autonomous, self-determined motivation. For instance, exposure to computer simulations would improve students' understanding of the structures and functions of machines and increase their level of competence in the topic. In addition, to give greater autonomy support to the students, the simulations were uploaded in the institution's intranet to enable the students to view the simulations at their own convenience. Finally, it was predicted that the computer simulations would initiate further discussions and interactions among students, thus enhancing their sense of relatedness within the cohort.

SBL provides a simulation environment that closely resembles the physical system, and hence enables learners to explore situations that would have been unattainable or too risky in real contexts. These virtual environments are usually interactive visualizations whereby learners can change input variables through data entry or manipulation of visual objects. They are then able to observe the consequences of these modifications through numeric displays, text labels, and changes in the visualization environment. Since there were no simulations catering specifically for the requirements of this course, simulations on the functioning of machines such as those involved in milling, turning, and drilling machines were therefore developed by some members of the project group. Each simulation showed a digital replica of one of these machines, which students routinely learned to manipulate in workshop practice. Traditionally, as for the Control group, the components and functions of these machines were explained during the weekly two-hour lectures. For the Experimental group, the two-hour lectures were shortened to one and a half hours to allow for a half-hour SBL session in the computer laboratory.

The main objective of the SBL modules was to give students a pre-workshop experience where they could gain insight on what they would encounter in the actual workshop. The modules were designed to enable students' familiarization with the experiments in order that they could improve their skills, gain confidence, and have greater awareness of safety procedures prior to carrying out the actual tasks. The simulations were not designed to provide a replacement for classroom teaching but rather to complement the latter. Hence, the simulations would help to increase the level of fidelity needed in an effective learning experience by reinforcing safety measures, operational procedures, and the combined output of the various machines towards the final product.

The simulations comprised three main domains of learning, termed "Explore," "Practice," and "Assessment." Figure 2 shows screen captures of the three domains based on the turning machine. The Explore domain allowed students to explore the digital replica of each machine, the various component parts, and how they could use them to perform various tasks. When launched, the simulation led the users through a guided exploration of the virtual environment enabling them to interact with the various parts of the machines in order to understand their functionality. The Practice domain provided guidance to students on specific machine operations. These simulations ran in a procedural manner with opportunities for students to activate and observe the various machining processes, such as those carried out by the drilling, milling, turning, bending, and shearing machines. For example, in the simulation on the turning (lathe) machine, operations such as facing, turning, centre drilling, deep drilling, and parting-off were demonstrated. For both the Explore and Practice modules, the students were guided by on-screen texts leading them through an interactive exploration of the machine

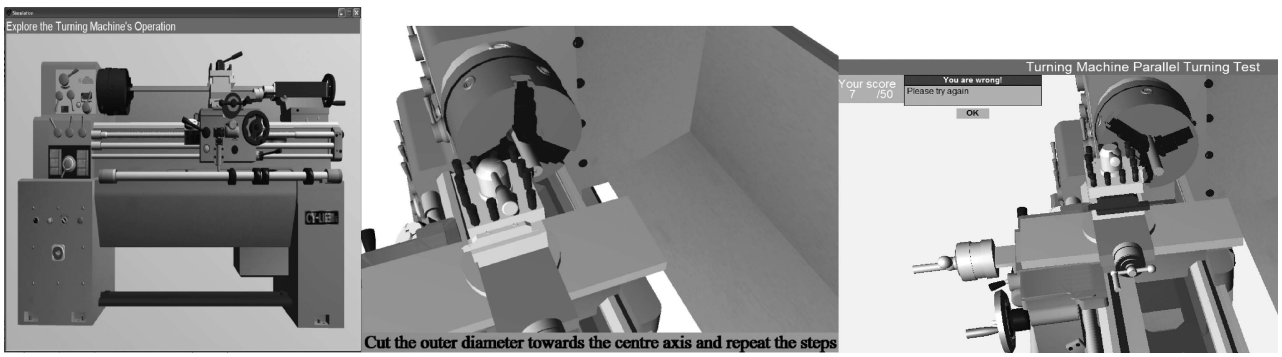

Figure 2. Screen captures of the Explore, Practice, and Assessment domains on the operations of the turning machine.

components and the operations of the various machining processes such as facing, turning, and drilling. Finally, the Assessment domain allowed students to perform self-assessment on the machine operations. The students were able to test their understanding of individual operations or combinations of machines and operations.

During the intervention period lasting six weeks, the same curriculum content was delivered to both the Control and the Experimental groups. The duration of the weekly lessons, a total of four hours, was the same for both groups. The students in the Control group had the conventional chalk-and-talk lectures (two hours per session), while the Experimental group had the benefit of SBL sessions (thirty minutes per session), but shortened conventional lectures (one hour and thirty minutes per session). Both groups had weekly, two-hour sessions of workshop practice in Machining Technology. Course instructors were responsible for the delivery of the lectures and the provision of technical assistance for operating the computer simulations. A number of technical support officers supervised the students during workshop practice. Although it was originally intended for students to work individually on the simulations, the students had the leeway to discuss with one another or to form working groups. Beyond curriculum time, students in the Experimental group had online access to the simulations whereas students in the Control group used conventional resources, such as lecture notes and textbooks to assist them in reviewing their work.

C. Assessing Students' Motivation and Learning Orientation

Following the intervention procedure, a 47-item survey was conducted with both the Control and Experimental groups to explore the students' perceived basic psychological needs satisfaction, motivation, and learning orientation. We used five-point Likert-type scales, ranging from one (strongly disagree) to five (strongly agree), for item scoring. The survey items, corresponding to 11 subscales, were adapted from a number of established instruments that were used and validated by other researchers. Thus, for the self-efficacy subscale, six items (e.g., "I am sure that I can do a good job if I am given a similar task to the one assigned for this class") were adapted from the General Self-efficacy scale by Schwarzer and Jerusalem (1995). Likewise, four items to assess self-regulation (e.g., "When studying the subject materials, I stop once in a while and go over what I have learned") and eight items to assess metacognition (e.g., "The subject material allows me to perform self assessment before moving on to the next task") were taken from the scale developed by Pintrinch and De Groot (1990). Five items were adapted from the Academic Self-Regulation Questionnaire (SRQ-A, Ryan and Connell, 1989) for the measurement of intrinsic motivation (e.g., "I enjoyed doing the subject activities"). Extrinsic motivation was assessed in terms of three types of motivational regulations, namely external regulation (two items e.g., "I do my work in this subject because I'll get in trouble if I don't"), introjected regulation (two items e.g., "I do my work in this subject because I want the instructor to think I'm a good student"), identified regulation (four items e.g., "I do my work in this subject because it is important to me"). These, together with three more items to measure amotivation (e.g., "I do my work in this subject but I don't see the need for it"), were adapted from the SRQ-A and from a modified version of Harter's (1981) scale for the measure of individual differences in motivation (Lepper, Corpus and Iyengar, 2005). To assess students' perceived satisfaction of the psychological needs, we adapted five items on autonomy support (e.g., "Aside from safety considerations, I was given freedom to work on my tasks") from the Learning Climate Questionnaire (Williams and Deci, 1996), five items on competence (e.g., "I feel confident in my ability to learn from the subject material") and three items on relatedness (e.g., "I felt like I could really trust the people I met in this subject") from the Intrinsic Motivation Inventory (IMI, McAuley, Duncan and Tammen, 1989). Cronbach's alpha was computed to assess the internal consistencies of the subscales.

The survey was administered in a quiet classroom environment under the supervision of the researchers and their assistants. The participants were given an hour to complete the questionnaire. We followed standard informed consent and ethical procedures conforming to the guidelines of the British Psychological Society. The participants were assured of the confidentiality of their responses and encouraged to give honest answers and to seek clarifications from the survey administrators if necessary. They were informed that the purpose of the survey was to gather information on the effectiveness of the learning strategies used in the Machining Technology course and that their feedback will be used for research in that field.

D. Assessing Students' Performance

A post-intervention quiz was administered to both the Control and Experimental groups at the end of the intervention period. The purpose of the quiz was to assess the effect of the SBL intervention on students' understanding and application of what they had learned. In the quiz, the students were shown diagrams of two parts of a simple tool. They were asked to propose a process plan to manufacture one of the two given parts and to give detailed descriptions of the types of machines used, the machining parameters, operations and safety measures to be undertaken. They were given the options to illustrate their plans with sketches, flow charts, or tabulations.

The students' scripts were then marked and the scores used to compare the performance of the Control group students with that of their peers in the Experimental group. To promote consistency in scoring, all the scripts were marked by a single assessor (a domain expert) using a set rubric in which marks were allocated according to the number of correct processes described and the quality of the students' responses. Thus, students could score a minimum of 1 mark and a maximum of 10 on the post-test. The quiz was scored blindly with the identity of the candidate withheld to avoid scorer bias.

E. Data Analysis

In the preliminary analyses, we computed the overall means and standard deviations of the sample as well as the Cronbach's alphas of the survey subscales. In the primary analyses, we conducted: (i) an independent-samples t-test between mean scores of the Control and Experimental groups, and (ii) a Pearson bivariate correlation analysis to assess any correlations between the subscales in the survey. In addition, we also carried out a multivariate analysis of variance (MANOVA) to examine differences between the responses of the different categories of students (international, GCE-O, ITE) and of the two genders in the Experimental and Control groups. Our analyses of the post-intervention test outcomes of students' achievement involved the administration of (i) a t-test for differences between Control and Experimental group scores, (ii) a one-way ANOVA for score differences between the three categories of students in the Experimental group, and (iii) t-tests for differences between male and female students in the Control and Experimental groups.

	Experimental		Control		Cronbach's
Subscale	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% (0.05) level between Control and Experimental groups.

Table 2. Descriptive statistics and alpha coefficients.

III. Results

A. Descriptive Statistics from the Survey Data

Table 2 shows the mean and standard deviation for the perceived needs satisfaction and motivation subscales. High mean scores indicate positive needs satisfaction and enhanced motivation. In this study, mean scores ($\bar{x}$) equal to or below 2 ($\bar{x} \leq 2$) are designated as low since on the Likert-type scales scores ranging from 1 to 2 imply that the subject disagrees with the statement of perceived satisfaction and hence feels that his or her basic needs are not met. Moderate mean scores, $2 < \bar{x} \leq 3$, imply that the subject holds a neutral view about his or her perceived needs satisfaction. High mean scores, those above 3 ($\bar{x} > 3$) imply that the subject agrees with a perceived satisfaction of basic psychological needs. As shown in Table 2, the students in both the Control and Experimental groups perceived high satisfaction for all three psychological needs. The Experimental group perceived highest satisfaction of the need for competence (3.820), whereas the Control group's highest perceived satisfaction was for autonomy support (3.849). Both the Control and Experimental groups perceived lowest satisfaction in the need for relatedness.

In terms of their motivation, the mean scores of both the Experimental and Control groups were in the moderate range for amotivation, external, and introjected regulations, but high mean scores were obtained for identified regulation and intrinsic motivation. Both the Experimental and Control groups indicated high self-efficacy, self-regulation, and metacognition for learning orientation. The Experimental group also obtained higher means than the Control group for subscales such as perceived relatedness, perceived competence, introjected regulation, self-efficacy, and self regulation.

However, the independent samples t-test, with equal variances assumed (Levene's test, $p > 0.05$), showed that the overall scores for the Experimental group were not significantly different from those of the Control group ($p > 0$ .05), except for perceived autonomy support, for which the scores of the Experimental group (M = 3.583; SD = 0.6478) were significantly lower than those of the Control group (M = 3.849; SD = 0.4615): t (112) = 2.389; $p <$ 0.05 (two-tailed). Cohen's $d = -0.473$, a small effect. Values of Cronbach's alpha were in the acceptable range (>0.70) for all subscales, showing good internal consistency between the items within each variable, except for external regulation ($\alpha = 0.596$).

B. Correlates of Perceived Needs Satisfaction, Motivation, and Learning Outcomes

Table 3 presents the correlations between the variables used. For the interpretation of the correlation coefficients (Cohen, 1988), low correlation is taken as $-0.30 < r \leq 0.00$ and $0.00 \leq r < 0.30$; moderate correlation as $-0.50 < r \leq -0.30$ and $0.30 \leq r < 0.50$; high correlation as $-1.00 < r \leq -0.50$ and $0.50 \leq r < 1.00$. Moderate to high correlations were obtained between the three psychological needs. The more autonomous forms of motivation, such as identified regulation and intrinsic motivation, showed strong, positive correlations with the three psychological needs. Learning orientations such as metacognition and self-regulation showed close association with the three psychological needs, as well as identified regulation and intrinsic motivation. There was strong association between self-efficacy and competence.

C. Survey Outcomes from International, GCE-O, and ITE Students

The descriptive statistics for the Experimental group showed that, of the three categories of students the International students produced the highest mean scores for perceived autonomy (M = 3.692; SD = 0.531) and external regulation (M = 2.692; SD = 0.895); the GCE-O students had the highest mean scores for perceived competence (M = 4.220; SD = 0.457), identified regulation (M = 4.125; SD = 0.710), intrinsic motivation (M = 3.880; SD = 0.491), self-efficacy (M = 4.101; SD = 0.561), and metacognition (M = 3.728; SD = 0.695); the ITE students had the highest means for perceived relatedness (M = 3.677; SD = 0.716), amotivation (M = 2.448; SD = 0.828), introjected regulation (M = 2.516; SD = 0.962), and self-regulation (M = 3.500; SD = 0.660). For the Control group, the GCE-O group had the highest mean scores in all subscales while the International students showed the lowest mean scores in all subscales except relatedness for which the ITE students had the lowest mean.

The results of the Experimental group MANOVA showed F to be significant at the 0.05 level: Pillai's Trace = 0.484; $F(22, 114) = 1.653$; $p < 0.05$; $\eta^2 = 0.242$. The univariate tests of between-subjects effects for each survey subscale showed the following: (i) the between-groups difference in terms of perceived psychological needs satisfaction was highest for competence ($F = 2.853$; $\eta^2 = 0.080$) and lowest for autonomy support ($F = 0.600$; $\eta^2 = 0.018$); (ii) in terms of motivation, the highest differential between the student groups was obtained with amotivation ($F = 4.909$; $\eta^2 = 0.129$) and the lowest with identified regulation ($F = 0.221$; $\eta^2 = 0.007$); (iii) for their learning orientation, the student groups differed most in terms of self-efficacy ($F = 3.837$; $\eta^2 = 0.104$) and least in metacognition ($F = 0.198$; $\eta^2 = 0.006$). However, the between-group effects showed significant differences only for amotivation ($F = 4.909$; $p < 0.05$) and self-efficacy ($F = 3.837$; $p < 0.05$). Post hoc comparisons with the Tukey HSD test showed that for amotivation there were significant differences when comparing GCE-O students with ITE students ($p < 0.05$, $\alpha = 0.05$) but no significant differences were obtained when comparing International students with either ITE students or GCE-O students ($p > 0.05$). For self-efficacy, significant differences were observed between GCE-O and International students ($p < 0.05$) but not between ITE and either of the two other groups. In terms of perceived competence, no significant differences were observed between ITE and either GCE-O or International groups, but differences were marginally significant ($p = 0.051$) between GCE-O and International students.

The results of the Control group MANOVA showed F to be not significant at the 0.05 level: Pillai's Trace = 0.436; $F(22, 66) = 0.837$; $p > 0.05$; $\eta^2 = 0.218$. This indicates that the between-groups differences between the Control group International, GCE-O and ITE students were not significant.

D. Gender Effects on Survey Outcomes

The results of the Experimental group MANOVA showed F to be significant beyond the 0.05 level: Pillai's Trace = 0.299; $F(11, 57) = 2.211$; $p < 0.05$; $\eta^2 = 0.299$. This indicates that there were significant differences between the male students' survey responses and those of their female counterparts.

For the Control, F was not significant beyond the 0.05 level: Pillai's Trace = 0.182; $F(11, 33)$; $p > 0.05$; $\eta^2 = 0.182$, showing no significant gender differences.

E. Performance Test Outcomes

The results of the t-test showed that the scores of the Experimental group (M = 4.441; SD = 2.494) were significantly higher than those of the Control group (M = 3.478; SD = 2.538); equal variances assumed (Levene's test, $p > 0.05$); $t(111) = 1.996$; $p < 0.05$ (two-tailed). Cohen's $d = 0.383$, a small effect.

Table 4 shows the descriptive statistics for the International, GCE-O and ITE students from the Experimental and Control groups. For the Experimental group, the results of the one-way ANOVA showed F to be significant beyond the 0.01 level: $F(2, 65) = 9.870$; $p < 0.01$; $\eta^2 = 0.233$. Post hoc comparisons with the Tukey HSD test shows that there are significant differences when comparing GCE-O students with either International ($p = 0.000$) or ITE ($p = 0.008$) students, although no significant

	Autonomy	Competence	Relatedness	Amotivation	External	Introjected	Identified	Intrinsic	Self-efficacy	Self-regulation	Meta-cognition
Autonomy	1	0.677**	0.449**	−0.170	−0.069	0.101	0.714**	0.6 05**	0.568**	0.425**	0.779**
Competence	0.416**	1	0.473**	−0.200	0.002	0.237	0.596**	0.659**	0.728**	0.437**	0.793**
Relatedness	0.587**	0.347**	1	−0.091	0.075	0.325*	0.551**	0.396**	0.377*	0.342*	0.436**
Amotivation	−0.295*	−0.507**	−0.243*	1	0.497**	0.564**	−0.288	−0.548**	−0.156	0.114	−0.235
External	0.182	−0.043	0.123	0.272*	1	0.643**	−0.018	−0.252	−0.012	0.331*	0.001
Introjected	0.354**	0.194	0.382**	0.040	0.608**	1	.004	−0.091	0.142	0.375*	0.122
Identified	0.530**	0.514**	0.485**	−0.437**	0.068	0.226	1	0.773**	0.486**	0.493**	0.757**
Intrinsic	0.590**	0.730**	0.637**	−0.581**	0.019	0.320**	0.622**	1	0.474**	0.396**	0.688**
Self-efficacy	0.319**	0.775**	0.237*	−0.346**	−0.039	0.072	0.336**	0.587**	1	0.422**	0.652**
Self-regulation	0.486**	0.300*	0.614**	−0.151	0.187	0.319**	0.576**	0.450**	0.261*	1	0.550**
Metacognition	0.679**	0.671**	0.548**	−0.390**	0.127	0.337**	0.613**	0.655**	0.413**	0.553**	1

*P < 0.05 **P < 0.01, Correlation Coefficients for the Experimental Group are presented below the diagonal and for the Control above the diagonal.

Table 3. Correlation matrix of the variables.

	Experimental group			Control group		
Student	Mean scores (M)	SD	N	Mean scores (M)	SD	N
International	3.32	1.547	25	2.23	2.229	11
GCEO	7.00	2.494	10	2.50	2.291	3
ITE	4.52	2.539	33	4.02	2.545	31
Total	4.44	2.494	68*	3.48	2.538	45

*One student was absent for the test.

Table 4. Descriptive statistics for Experimental and Control group achievement test scores.

	Experimental group			Control group		
Student	Mean scores (M)	SD	N	Mean scores (M)	SD	N
Male	4.82	2.644	51	3.94	2.552	31
Female	3.29	1.532	17	2.464	2.274	14
Total	4.44	2.494	68	3.48	2.538	45

Table 5. Descriptive statistics for gender differences in achievement test scores.

differences were obtained between International and ITE students ($p = 0.113$). For the Control group, the results of the one-way ANOVA showed F to be not significant beyond the 0.05 level: $F(2, 42) = 2.398$; $p > 0.05$; $\eta^2 = 0.102$.

Table 5 shows the descriptive statistics for the male and female students from the Experimental and Control groups. For the Experimental group, the results of the t-test showed that the scores of the male students (M =4.82; SD = 2.644) were significantly higher than those of the female students (M = 3.29; SD =1.532): equal variances assumed (Levene's test, $p > 0.05$); $t(66) = 2.255$; $p < 0.05$ (two-tailed). Cohen's $d = 0.708$, a medium effect. However, for the Control group, the *t*-test showed no significant differences between the mean score of the males (M = 3.94; SD = 2.552) and that of the females (M = 2.46; SD = 2.274).

IV. Discussion

A. General Outcomes

Our findings suggest that the students in both the Control and Experimental groups perceived their psychological needs to be satisfied with the Control group experiencing highest satisfaction in autonomy support and the Experimental group in competence. 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 for competence and autonomy support (Liu and 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 Control and Experimental groups) and that students who experienced SBL (Experimental group) perceived higher competence than their peers in the Control group. However, the Experimental group expressed significantly lower satisfaction in autonomy support than the Control 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 due to 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 Experimental 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 (Moshaiov, 2005) 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.

Both the Control and Experimental 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. Thus, it is not surprising that both the Experimental and Control groups showed high perceived self-efficacy and metacognition. However, whereas the Experimental group had high self-regulation, the Control group obtained lower mean scores than their counterparts in the Experimental group, suggesting that although both groups had confidence in their abilities to meet the demands of the course, SBL might have inculcated greater self-regulation amongst the students in the Experimental 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 Experimental and Control 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 (six weekly sessions of thirty minutes each) to SBL, which could have been inadequate in this particular context to produce significant effects. We designed simulations of thirty minute duration based on previous research showing that these were sufficient in promoting good performance (Lane and Tang, 2000). However, in the current context, the six weeks' intervention may not have been sufficient to contribute significantly to changes in students' perception of a complex construct, such as motivation. Future work could focus on extending SBL to more modules in the engineering program, thus allowing more students to experience SBL over a longer time span.

B. Correlates of Perceived Psychological Needs, Motivation, and Learning Orientation

Moderate to high correlations were obtained between the three psychological needs. For the Control group, autonomy support correlated highly with competence, which suggests that in a conventional class setting students tend to feel more competent when they are given adequate autonomy in their learning. In the Experimental group, however, autonomy support correlated highly with relatedness given that these students' perceived low satisfactions for both autonomy support and relatedness. Hence, for these students, a less restrictive environment and more autonomy may foster a greater sense of belonging to their groups.

Both groups showed high correlations between autonomy support, competence, and the more autonomous forms of motivation such as identified regulation and intrinsic motivation. Generally, low-to-moderate correlation was observed between the three psychological needs and the types of extrinsic motivation such as external and introjected regulations. This is in accordance with the Self-determination construct, which relates perceived needs satisfaction to the more autonomous forms of motivation. Relatedness correlated strongly with identified regulation for the Control group but with intrinsic motivation for the Experimental group. This suggests that motivation within the Control group may arise from a collective understanding of the value of the engineering module, whereas for the Experimental group relatedness and shared interest in the subject may have led to intrinsic motivation amongst its members. Amotivation correlated negatively with the three psychological needs with the strongest negative correlates obtained with the Experimental group, particularly for the competence subscale showing that perceived lack of competence ultimately led to no motivation.

Correlates of perceived psychological needs and learning orientation showed that for both the Experimental and the Control groups there was a high correlation between self-efficacy and competence, indicative of self-perceived competence being a prerequisite for the belief in one's ability to carry out a task to completion. In addition, the Experimental group showed high correlation between (i) self-regulation and relatedness and (ii) metacognition and all three psychological needs. For the Control group, correlations were (i) moderate between self-regulation and all three psychological needs, and (iii) high between metacognition and the needs for autonomy support and competence. This reaffirms previous research reporting that self-regulation (Ryan et al., 1985) and metacognition (Koh et al., 2009) are promoted when basic psychological needs are satisfied.

C. Comparing Needs Satisfaction, Motivation, Learning Outcomes, and Post-test Results of Students from Diverse Backgrounds

From the descriptive statistics, we found that the International students in the Control group had low mean scores in almost all subscales, whereas those in the Experimental group ranked highest in terms of autonomy support and external regulation. The course instructors observed that the international students seemed to prefer to work on their own or with their fellow citizens, hence their perceived satisfaction of autonomy. A possible explanation is that these students came to Singapore with the objective of obtaining the necessary paper qualifications that would improve their future job prospects. It is understandable that they would show a propensity for external reward orientation. The Experimental group GCE-O graduates, on the other hand, showed the highest mean scores for metacognition and perceived competence. A rigorous four-year secondary school program (high school equivalent) would probably have made these students most confident in terms of their competence in the subject. This might explain their high level of self-determined motivation, their top scores in identified regulation and intrinsic motivation indicating that most of these students valued their course and/or were innately interested in it. As for the Experimental group ITE students, they showed the highest scores in amotivation and introjected regulation, indicating that they were in need of further assistance in improving their motivation in the course. However, these students were ranked highest in terms of their perceived relatedness and self-regulation in contrast to their Control group counterparts who scored lowest for relatedness. This suggests that although the SBL experience did not improve self-determined motivation amongst the ITE students, it nevertheless fostered improved relationships amongst them, thus assisting in their self-regulation.

The Experimental group MANOVA results showed that there were differences between the International, the GCE-O and the ITE students in terms of both their survey responses and post-intervention quiz results. The three categories of students (International, GCE-O and ITE) differed most in their perceptions of competence, self-efficacy and their degree of amotivation. The least variance was observed for the students' perceptions of autonomy support, identified regulation and metacognition. The GCE-O students showed significantly higher motivation than their ITE

classmates, and significantly higher post-intervention quiz scores than either ITE or International students. No significant differences were observed amongst the three categories of students in the Control group, suggesting that SBL had a positive impact on motivation and performance attainment, at least for the GCE-O students.

D. Gender Differences in Survey Outcomes and Achievement test scores

There were significant differences between the survey responses of the male students and those of their female classmates. In addition, the males in the Experimental group achieved a significantly higher mean score than the females in the post-intervention quiz. However, for the Control group, there were no significant differences between males and females in terms of survey responses and performance test scores. This seems to indicate that the SBL experience had a higher positive impact on the male students than on their female counterparts. However, we are cognizant of the fact that the small sample size of the female students in both the Experimental and Control groups might compromise the generalizability of this conclusion. Yet, the female students comprise about 36 percent of the participants in this study and hence constitute a good representation of the general proportion of female engineers—17 percent in Singapore, 20 percent in the USA and 15 percent in Australia (Ang, 2006; Horting, 2006; Carrington and Pratt, 2003). As such, although these findings may not be applicable to all contexts, they nevertheless point to potential areas of improvement in the current instructional practices.

E. Implications for the Use of SBL in Engineering Courses

These findings imply that SBL may have differential effects on learners depending on factors such as gender, educational backgrounds, and IT knowledge. SBL seemed to have benefited male students and GCE-O graduates most. This is likely to be due to their familiarity with and affinity for computer-assisted learning and the fact that the GCE-O program provided students with a good grounding for higher education. However, the International and ITE students did not seem to benefit from SBL to the same extent as their GCE-O classmates. Some of these students might not have had adequate exposure to the use of IT as a learning tool, and hence viewed SBL as a source of "extra work", preferring to adhere to traditional approaches of learning. Yet others may have done badly in the post-intervention quiz due to their low language proficiency and their inability to give comprehensive answers to the test questions. When asked to describe some of the foreign and ITE students' performances in the quizes, the test scorer gave comments such as "not able to use correct technical word", "general description —not clear", and "identified the features but cannot explain the process". Hence, teaching staff should be aware that some students, though fully cognizant of the requirements of the task at hand, may not be able to perform to expectations due to their poor language proficiency. A possible solution to this problem is to include a practice-based component to the post-intervention test. For instance, other than the traditional paper-and-pencil test, students could be asked to execute their proposed process plan, thus enabling course instructors to assess them on their skills in manipulating the various tools and in making appropriate use of the various machines.

The lower achievement of the female students as compared to their male classmates in the post-intervention quiz suggests that we should consider strategies to even out this discrepancy in performance. Many authors have highlighted the under-representation of females in engineering as well as their lower interest and performance in this field as compared to their male peers (Anderson and Gilbride, 2007; Lemons and Parzinger, 2007; Trenor et al., 2008). Suggested reasons for these discrepancies include lack of awareness of engineering as a career and field of study, gender schemas of engineering as an 'all-male' domain, social and contextual factors, gender differences in early childhood nurturing, and biased attitudes of male peers and teaching staff. There are certainly many ways in which the predicaments of our female engineering students can be alleviated. Anderson and Gilbride (2007) suggested the implementation of engineering awareness programs that could include talks and activities conducted in schools to familiarize students with the nature of engineering and its prerequisites. In addition, the schools and tertiary institutions could provide a more supportive learning environment for female engineering students by reducing any form of bias and encouraging cross-gender collaboration. For instance, when conducting project tasks, students should be encouraged to work in heterogenous groups comprising male and female members instead of single gender groups.

Finally, although there is a possibility that the differences in performance outcomes between the Experimental group and the Control could be due to more time spent on task rather than from the SBL experience, one could argue that the duration of formal lessons was the same, a total of 4 hours per week for both groups. Furthermore, students in the Control could have spent as much time reviewing the course materials from their textbooks or lecture notes as the Experimental group students did using SBL.

F. Limitations of the study

We recognize that there are a number of limitations to the study. First, due to time constraints for the administration of the survey instrument, the number of items in some of the subscales (e.g., the various types of extrinsic motivation) was kept to a minimum. This may have contributed to the low internal reliability of one of the subscales (i.e., external regulation, $\alpha = 0.596$).

Second, we had a relatively small sample size and the Experimental and Control groups had different proportions of the three student categories (International, GCE-O and ITE). This differential representation could have interfered with our research outcomes and obscured the actual impact of SBL. Unfortunately, these were practical constraints imposed by the nature and size of the yearly student intake and the numbers registered for our particular module in the engineering program. One way forward would be to extend the practice of SBL to more modules, hence ensuring an increase in sample size and hopefully evening out student distribution.

Finally, this study could be extended to other tertiary institutions (such as universities and other polytechnics) in Singapore and in other Asian countries to enable broader generalizations to be made to the current findings. Further research also warrants a comparative study undertaken in the western context, as motivational constructs are likely to differ between Asian students and their western counterparts.

V. Conclusions

This paper explored the extent to which 3D simulation-based learning affected polytechnic engineering students' perceived

satisfaction of psychological needs, motivation, learning orientation, and performance attainment. Our findings suggest that the engineering students perceived their basic needs for competence, relatedness, and autonomy support were met. Likewise, this study indicates that SBL can potentially enhance self-determined motivational regulations as well as better understanding and application of learning. However, we found that the effects of SBL on students varied in accordance to their educational background, gender, and familiarity with IT. This is of significance to engineering educators and program developers since the effectiveness of a new strategy (such as SBL) may be hampered by latent factors including language difficulties, gender bias, and lack of competence in IT usage. Prior to the implementation of new approaches to teaching and learning, due consideration should be given to the different profiles and needs of the students. Measures should be undertaken to ensure that all students are given sufficient help to overcome any constraints to their progress in the course.

Our work has provided insights on the impact of SBL on students' motivation and learning and the issues arising from adopting such a strategy. For more conclusive results, further research warrants the use of an improved measurement scale and an extended intervention program applied to a larger participant sample.

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