IMPACT OF SPATIAL ABILITY TRAINING AND ITS TRANSFER

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ABSTRACT

This study was undertaken to examine students' perceived ability to learn basic engineering drawing, differential impacts of spatial training and training transfers. The research method used was based on the Triangulation Software Development Method, which was carried out in two parts: a Survey Research, and an Experimental Research. The survey research examined students' perceived ability in learning engineering drawing involving 355 secondary school pupils, with a mean age of 15.5 years, which was conducted through a survey. The independent variables of the survey research were spatial experience, gender and mathematical ability; the dependent variable was the perceived ability. Instruments used were Students Perception Questionnaire (SPQ) and Spatial Experience Questionnaire (SEQ). The experimental research was based on pretest-posttest design, which was carried out to examine the extent of Spatial Visualization (SV) and Mental Rotation (MR) training improvement, differential impacts attributed to gender and training method, and training transfer to engineering drawing task. Ninety-eight secondary school pupils (36 girls, 62 boys), with a mean age 15.5 years, were randomly assigned into two experimental groups and one control group. The first experimental group employed interaction-based training in a desktop virtual environment trainer, the second group used animation-based training, and the control group trained using printed materials and all groups trained for 6 weeks. Instruments used were computerized version of the Spatial Visualization (SV) and Mental Rotation (MR) tests. All data collected were analyzed using SPSS version 18. For the survey research, correlations among spatial experience, gender, and mathematics achievement with students' perceived ability to learn were significant. In general, high spatial experience respondents, boys, and high mathematics achievers tended to view the learning favorably. Several topics of engineering drawing were found to be particularly difficult namely orthographic drawing and isometric drawing. For the experimental research, analysis of the data revealed that there were substantial performance gains in SV and MR accuracy, but not in MR speed. Main effects of training in SV and MR accuracy were found; those trained using novel methods, especially in the interaction-enabled method, outperformed those trained in the conventional method.

Interaction effects were observed where differential improvement gains in SV and MR accuracy only involved boys but not girls. Transfer of training to performance in solving engineering drawing task was observed through differential performances of groups where those with higher spatial ability solved the task much better than those with lower spatial ability after spatial training. This transfer was qualified by the multiple linear regression procedure revealing that spatial visualization was found to be significant in predicting the performance of the basic engineering drawing task. Implications of the lessons learned and recommendations for future study are also discussed.

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CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter highlights the issues surrounding the teaching and learning of engineering drawing or engineering graphics informed through previous studies involving schools and colleges in Malaysia and other countries. Several issues emerged indicating that there is a myriad of problems involving conceptual, pedagogical, and student and teacher experiential factors affecting students' performance in this subject matter. One common problem that seems to confront student ability to follow the course in engineering drawing stems from the cognitive perspective suggesting that a prerequisite ability or skill is required. This ability or skill is generically termed as spatial ability is vital in learning domains that involve problem solving that taps on visualization and manipulation of visual-spatial information. This ability has been shown as a reliable predictor of success in engineering graphics instructions, with its impact probably surpassing other factors typically studied in relation to student performance in this course.

Recognizing its importance, several interventional methods have been developed to enhance students' spatial ability where some degrees of success have been reported after training sessions. One emerging technology prominently reported in recent studies involves learning and training in virtual environments where students had gained relatively better improvement compared to traditional methods. However, more specific and focused training of the critical components of spatial ability, particularly in spatial visualization and mental rotation (accuracy and speed measure), is needed to ensure relevant skills are properly addressed and trained to help students acquire the required spatial skills deemed vital in engineering drawing learning.

1.1 Background of the Research Study

The Ninth Malaysia Plan (NMP 2006 – 2010) implemented in year 2006 has envisioned a workforce that is technically and scientifically oriented in its quest to become industrialized nation by year 2020. About 500,000 professionals consisting of engineers, assistant engineers, architects, technologists and other specialists are urgently needed by the end of the decade (NMP 2006 – 2010, Chapter 4, p. 12). Creating this kind of workforce necessitates all relevant ministries to take pertinent measures to address these requirements and in particular the Ministry of Education (MoE) where its educational planning and implementation will have to undergo major and drastic transformation. A key objective of the plan has been the transformation of its existing industries into knowledge-based and high technology industries in order to achieve a vibrant, expanding economy. However, this highly ambitious vision would not be realizable if the nation's workforce at that point in time is lacking the relevant technical, scientific and engineering skills. Taking cognizance of the impending challenges, Malaysian government has carried out several proactive measures; and these include the current educational reform that emphasizes on upgrading the technical education at the secondary school level. Currently, there are 88 technical schools that offer various technical fields namely civil, mechanical and electrical engineering, which are located throughout the country, including Sabah and Sarawak. The number of this type of schools is expected to grow at a faster rate in view of the recent shift in the educational policy – a focus on technical training for future workforce.

Technology education or technological study is ‘a study of technology which provides an opportunity for students to learn about the processes and knowledge related to technology that is needed to solve problems and [to] extend human potential’ (ITEA , 2000, p. 242). The curriculum implemented in the technical schools consists of technical subjects that aim to prepare students with knowledge appropriate for basic engineering and technological skills. A particular subject merits attention is the *engineering drawing* subject that was initially introduced in nine technical secondary schools in 1992. The educational system for secondary schools in Malaysia had been revamped in the late 1993 that introduced *open certification system* as opposed to the previous closed certification system. The new open certification system called *Integrated Secondary School Curriculum* (*Kurikulum Bersepadu Sekolah Menengah, KBSM*) enables students at the national secondary schools (*Sekolah Menengah Kebangsaan, SMK*) to pursue compulsory or core subjects together with several elective packages. The introduction of technical subjects in these non-technical schools is a positive step taken by the MoE, having realized that technical institutional entities in Malaysia alone will not be able to prepare a highly technical workforce as needed (KPM, 1998)

Two technical subjects that are critical in preparing students to attain the crucial technical knowledge and skills are the engineering-related subjects: *engineering drawing* and *engineering technology* (KPM, 1998). The former subject was first introduced in 30 national secondary schools in 1993, and the implementation of the latter subject in 20 national secondary schools was carried in 1996 (Abu Bakar Hashim, 1995). In addition, engineering drawing is one of the KBSM electives in the second package of the vocational and technical grouping. Historically, engineering drawing was not a new subject offered at the technical secondary schools as it was actually a revised version from earlier courses – under different names – that essentially encompassed similar contents such as *Technical Drawing* (*Lukisan Teknik*) or *Geometrical and Building drawing* (*Lukisan Geometri dan Bangunan*) (Zainon Haroon, 1993). This subject featured prominently in these schools for students enrolled in various engineering disciplines such as civil, electrical, and mechanical. However, this subject, in its old version, had some drawbacks that were similar to other technology-oriented courses where the currency and relevancy of the technical curricula were trailing behind the fast-expanding technology. This problem is inherent in many technical disciplines, as these fields are intertwined with computing technology such as engineering, manufacturing, and design.

The new subject, namely engineering drawing is more focused and holistic as it was designed to fulfill the objectives of technical communications involving important engineering fields (i.e., civil, mechanical and electrical engineering). Having exposure to this knowledge domain is vital in developing students' awareness in a particular engineering field that interests them (KPM, 1998). The implementation of this subject in technical secondary schools was smooth as the existing conditions were conducive. However, the same was not true in the national secondary school; conditions that existed during the implementation were not conducive. For the technical schools, the implementation was merely a natural transition from old to new version of the subject matter where not much had changed in terms of teachers' proficiency, material resources and students' background. However, for the national secondary schools, the newly introduced subject had caused a host of problems from the start. Problems cropping up at the academic and administrative levels were not unexpected given the technical contents that are intellectually demanding and challenging, which many of this type of schools (by being non-technical secondary schools) had never experienced in handling the subject matter.

Successful implementations of new curricula with new courses or subjects in schools will depend on many interrelated factors. Many of the issues related to the implementations of the technical courses that have been studied invariably revolve around course contents, current pedagogy, teachers' preparation, teaching and learning environments, schools' infrastructure, and students' background. In concert, some of these factors will exert an overpowering impact that determines the success of new educational programs. Poignantly, the teaching and learning process of such new courses will present new, unfamiliar challengers to pupils, teachers, instructors, and even to administrators, and educational policy makers. Thus, for this reason, the introduction of engineering drawing in technical secondary schools in general and national secondary schools in particular is of great concern to many.

Several researchers have carried out several studies on the rate of success of this subject in relevant schools since its inception in 1993. Students' academic grades in the Malaysian Certificate of Education examination (equivalent to British O-level or American Middle Grade) were used as an indicator of success or failure for such an implementation. In this respect. the success rate for the engineering drawing introduced in year 1993 was high with 84.8% of the candidates had passed the examination; this was hardly surprising given the fact that only students in technical schools were involved. The technical students were expected to do well in view of their relatively higher academic performance. However, the following years till 1996 had witnessed a steady decline as the passing rates dropped to 60% passing rate. One of the main reasons was that students who learned this subject were not only those who studied in the technical schools, but pupils from the national secondary schools also pursued this subject; in general, the former were academically more proficient than the latter (Nor Fadila & Widad Othman, 1999).

Albeit the growing concerns, the year that followed saw a slight improvement, which recorded a modest 66% passing rate because several more newly established technical and science schools were involved in the implementation of this subject (LMMPT-SMA, 1998). With these new schools, the subject was then offered in three types of secondary schools: technical secondary schools, national secondary schools, and science secondary schools. The percentages of the passing rate based on the school categories were 89%, 75%, and 43% for science, technical and national secondary schools, respectively. Evidentially, students' performances were diverse based on the school categories; pupils from the science and technical secondary schools outperformed those from the national secondary school category. Similar trends of student performance is expected to persist at best or to drop drastically at worst as more national secondary schools will start offering the subject matter in the coming years.

1.2 Problem Statement

The current state of students' performances in engineering drawing subject has prompted several researchers to conduct several studies to identify factors that influence the process of teaching and learning of the subject matter. These researchers have investigated the challenges faced by teachers and instructors in implementing the new curriculum; more importantly, the researchers have embarked on studies to examine the effects of this implementation on the teaching and learning process, particularly focusing on students' performance (Nor Fadila & Widad Othman, 1999). Their findings revealed that there were several factors that have resulted in students' low performances: pupils' poor spatial ability (Ahmad Zamri, 2002;, Bektasli, 2006; Casey, Nuttall, Pezaris & Benbow,1995; Millroy & Rochford, 1985; Siemankowski & MacKnight, 1971), pupils' lack of drawing practice (Azaman, Ramlee, Shafie & Mohd Shahril, 2009; Widad Othman & Hatta Ismail, 2001), teachers' high teaching workload (Tuan Zaidi, 2002), teachers' lack of instructional experience (LMMPT-SMA,1998; Sorby & Baartmans, 1996), and gender-related learning issues favoring boys (Strong & Smith, 2002; Tartre, 1990).

Among the contributing factors, spatial ability or spatial skill of pupils is believed to be an indicator of students' performance; those with poor or inadequate spatial ability can be a detrimental to successful learning. Learning difficulties will be self-evident when poor spatial pupils start learning the core topics of engineering drawing: orthographic views, isometric views and auxiliary views. Their inability to follow the instructions of these highly demanding spatial topics will be apparent with their slow progress in developing the proper reasoning in solving spatial tasks assigned to them. To make matter even more problematic, gender factor has been shown to be a variable that could result in performance disparity, with boys in general outperforming girls. This gender disparity in engineering drawing performance is the outcome of differential levels of spatial skills that individuals might have, with boys having better spatial ability than girls do. Seen from another perspective, a host of experiential or environmental factors rather than biological factors might have shaped one's spatial ability level.

From the teaching environment perspective, many factors prevailing in the classrooms are not helping in creating conducive, supportive learning environments. Invariably, current teaching style is typically teacher-centered, relying too much on instructions that leave many pupils with a lack of opportunities to engage in personalized knowledge construction. Tight teaching schedule and over-emphasis on finishing the school curricula have made the problem even worse; the former results in teachers not giving enough attention to pupils' needs, and the latter makes teachers less focused on engineering drawing teaching as they have to deal with other subjects as well.

Findings from studies conducted in Malaysian schools to date have shed some lights regarding the challenges and problems faced by teachers and students in the implementation of a technology curriculum in particular engineering drawing. Studies carried out by the researchers encompass a range of issues involving cognitive and pedagogic domains, namely conceptual learning, students' experiences, teachers' experiences, and spatial ability in the teaching and learning process. Pedagogical aspects of engineering drawing instructions have been given much attention by some researchers where most agree that multiple- and flexible-instructional strategies assisted by information and multimedia technologies should be employed in the teaching process (Azaman Ishar et al., 2009; Othman & Kamaruzaman, 1995; Tuan Zaidi, 2002).

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Being a relatively new subject in the school curriculum has unraveled many problems associated with the teaching and learning process. Students with different academic, school, and gender backgrounds have been observed to exhibit diverse spatial visualization ability, thus requiring appropriate instructional approaches to facilitate their learning (Nor Fadila & Widad Othman, 1999). Consequentially, some students would encounter an array of learning problems or challenges given their shortcomings and drawbacks in this ability; thus, these problems warrant an immediate, effective remedy and intervention to mitigate the difficulties. More importantly, low spatial students

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must be given sufficient training or learning opportunities to improve their spatial skills.

Taking cognizance of the imperative to improve students' spatial ability, new, novel methods of training have been experimented, yielding a wide spectrum of outcomes – both promising and discouraging. Current trend seems to use multimedia technologies and computer-mediated instructions as a spatial training platform. Of late, virtual reality, which is a new multimedia technology, has been shown to be a promising spatial training tool as demonstrated from recent studies by Cheong (1999), Dalgarno (2001, 2010), Kwon and Kim (2002), Mohler (2001), and Smith and Lee (2004). In spite of its apparent, euphoric appeal, it is still quite premature to conclude its educational impacts on spatial ability development training as virtual reality has still not been fully studied in many aspects of spatial skills training, as there is a diverse range of students' demography involved.

Due to the well-established research in the military applications, most educational studies that have been carried out so far are based on the immersive VR technology, which is complicated and expensive type of VR tool – beyond the reach of typical Malaysian schools. Research on desktop VR is scarce that augurs discouraging news to teachers and instructors, as this type of technology seems promising to be applied for spatial training for school children by being inexpensive, practical and capable of being used on a wider scale. Moreover, most studies that have been carried out thus far are also technology-centric (focusing on the technological dimensions), but the more important aspects related to instructional designs (supported by sound theoretical underpinnings) are unfortunately lacking.

1.3 Purpose of the Study

The discussion based on the review of the visio-spatial literature highlights a range of issues confronting the teaching and learning of engineering drawing. Demographic, psychological, and cognitive factors particularly gender, perceived ability (i.e., self-efficacy), and spatial ability exert strong impact in engineering drawing learning of secondary school students at the foundational year in Malaysia (Azaman et al., 2009; Jayasree, 2003; Othman & Kamaruzaman, 1995; Tuan Zaidi,2002). Gender seems to play an influential role where, in general, male pupils tend to view the learning of the subject matter more favorably than females. In addition, male pupils have attained relatively better examination grades than their opposite counterparts. Spatial experience of students also adds some weight in that there is a significant relation between the level of spatial activities students engaged and perceived ability or self-efficacy in learning engineering drawing. Another factor that has been determined to be influential is mathematical ability where significant correlation has been found between student's perceived ability to follow the engineering drawing instruction and this ability (Azaman et al., 2009; Nor Fadila & Widad Othman, 1999).

Performance of students in engineering drawing courses correlates significantly with students' spatial ability, namely spatial visualization and mental rotation as observed in previous studies (Shawn & Smith, 2002; Sutton & Williams, 2006; Sutton, Williams, & McBride, 2009a). These two abilities are very important in learning domains such as engineering, architecture, and graphics courses, which rely on spatial cognition for solving technical problems. A learner should possess a highly developed visual-spatial skill or ability to learn such courses successfully. Individual differences in spatial ability may affect learning outcomes where high spatial learners have been found consistently to outperform low spatial learners in most studies. In addition, male students possess higher spatial skills compared to female students owing to differential backgrounds in engagement of spatial activities that favors the former. Apparently, a high level of spatial experience would suggest that there would be more opportunities to practice spatial skills, which partly contribute toward greater development in spatial ability among boys compared to girls.

Two important themes emerged from the review of the literature that mainly focuses on students' overall perception of their learning in engineering drawing and their performance in the subject matter. The first part involves factors such as gender, spatial experience, and previous mathematic achievements in relation to perceived ability to learn the subject matter (Baartmans & Sorby, 1996; Bektasli, 2006; Nor Fadila & Widad Othman, 1999; Tracy, 1987;). The second part stresses the impact of demographics, namely gender and level of spatial ability on engineering drawing performance. In addition, methods of improving spatial ability have been rigorously studied given the significant association between this ability and the performance of engineering drawing tasks. The research study carried out by the author involved two main parts, requiring two approaches in the research design; the first part was implemented through a survey research, and the second part involved an experimental research to address the prevailing problems and issues in the learning of the subject matter.

The design of the survey research was based on the explanatory paradigm in that it sought to examine the relationships among important factors involving gender, spatial experience, and previous mathematic achievements with perceived ability to learn engineering drawing. The explanatory survey investigated whether the associations of the independent variables (i.e., gender, spatial experience, and previous mathematic achievement) and dependent