Assessing and Enhancing Visualization Skills of Engineering Students in Africa: A Comparative Study

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Abstract

Visualization skills are believed to be a strong indicator of success in engineering, science, and a variety of other careers. Previous studies have compared the visualization skills of first year engineering students in the US with their cohorts in Europe and Brazil, but to date there have been no data reported for developing countries in Africa. Studies have shown that training can enhance visualization skills in a relatively short time. This paper will report on the results of a study of first year engineering students at the Polytechnic of Namibia that have been exposed to a short course to improve visualization skills.

INTRODUCTION

Numerous studies have shown that spatial visualization skills are important to success in many fields of science and engineering (Hake, 2002; Hamlin et al., 2006; Hegarty & Kozhevnikov, 1999; Hsi, 1997; Miller & Bertoline, 1991; Pleck, 1991; Sorby, 2000). Factors that affect visualization skills include playing with construction toys, participation in certain sports, previous drafting experience, and gender (Gimmestad, 1990; Leopold, 2005; Silverman et al., 2007). These factors may also be affected by socio-economic and cultural differences. Thus we can anticipate that students entering engineering studies at African universities may have differing abilities when compared to their peers in the industrialized nations.

Engineering education is recognized as a key factor for the economic development of African countries (Mangena, 2006). As developing countries work towards improving their educational systems, it is imperative that they include elements in the curriculum to enhance skills which are critical to the success of students in engineering courses, including visualization skills.

BACKGROUND

This section includes information on the history of engineering at the Polytechnic of Namibia, recent changes in engineering graphics curricula, and a brief survey of instruments used to test visualization skills.

Polytechnic of Namibia – The Polytechnic of Namibia (PoN) was established in 1994, with roots from the former Technikon and College for Out-of-School Training. These institutions offered programs at the diploma and certificate level. The Polytechnic offers one- and two-year National Certificates, three-year Diploma and four-year Bachelor of Technology programs in civil, electrical (power), electronics, mining and mechanical engineering. The Bachelor of Engineering program for civil engineering was added

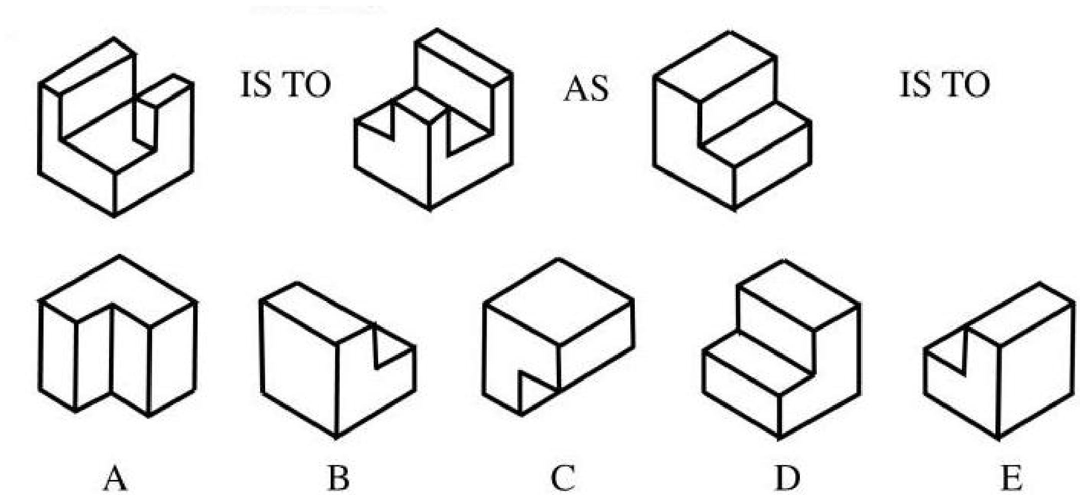

Figure 1. Example problem from the PSVT-R (adapted from Titus, 2009).

in 2008, and BE programs for electrical and mechanical engineering in 2009.

Recent Changes in Graphics Curricula – Researchers generally agree that spatial visualization skills are enhanced by sketching 3D and manipulating physical 3D objects. Traditionally, engineering graphics included a strong component of descriptive geometry and sketching. Since the advent of computer-aided design systems in the early 1980s, nearly all US engineering schools eliminated courses in descriptive geometry, and most schools also eliminated manual drafting and sketching in their introductory graphics courses. Universities around the world have followed suit. As a result, there has been a noticeable decline in the visualization skills of engineering students.

These changes may be further compounded by societal influences affecting incoming students. Children spend less time playing with manipulative toys, taking apart mechanical devices, and similar activities in favor of electronic toys and entertainment. Leopold (2005) reported that engineering students in 2004/5 entered university with poorer visualization skills than students entering a decade earlier.

Early studies indicated that CAD courses might enhance spatial skills (Miller, 1992); however, more recent studies indicate that 3D CAD experience alone does not seem to enhance visualization skills (Leopold, 2005; Sorby & Gorska, 1998; Sorby, 2000).

Tests to Measure Spatial Skills – Gorska and Sorby report on several visualization testing tools (2008). The Purdue Spatial Visualization Test (PSVT) includes three sections covering developments, object rotations and perspective rotations (Guay, 1977). Most graphics researchers use only the object rotations portion, PSVT-R. In this test, an example object is shown in two isometric views; a second object is presented with five alternative views, one of which represents the second object subjected to the same rotation as the example. A sample problem from the PSVT-R is shown in Figure 1.

Vandenburg and Cruz (1978) developed a Mental Rotations Test (MRT) which presents a criterion figure shown along with four candidate figures, two of which represent the criterion figure in a rotated position. An example question from the MRT is shown in Figure 2.

The Mental Cutting Test (CEEB, 1939) presents a 3D object with an imaginary cutting plane and five possible solutions for the cross-section shape, as shown in Figure 3. This test is widely used in Europe, Japan and the US.

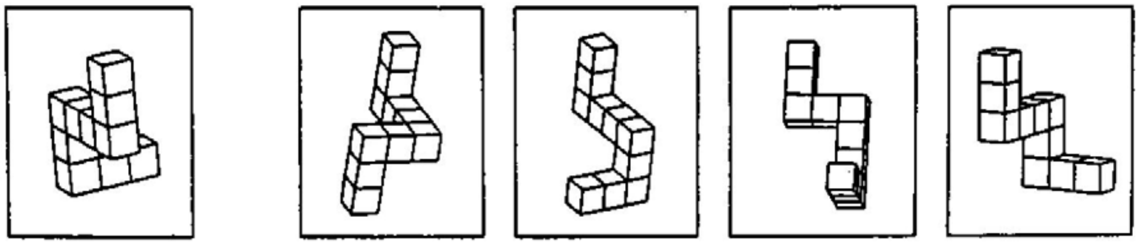

Figure 2. Example problem from the MRT (adapted from Peters, 1995).

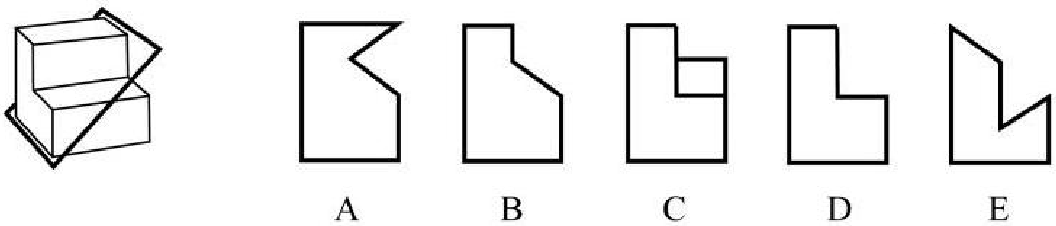

Figure 3. Example problem from the MCT (adapted from Titus, 2009).

INTERNATIONAL BENCHMARKING

Much work has been done in recent years to assess the spatial skills of engineering students. Table 1 shows results reported in the literature; most work has been reported by industrialized nations including the US, Australia, Japan, China, Poland, Germany, and Spain. Developing countries such as Brazil and Malaysia are also included, however, no information could be found regarding spatial skills assessment of any populations in Africa, including studies of the general population.

The sample populations in these studies represent incoming freshmen engineering students unless otherwise noted. Most US researchers have used the PSVT-R to measure visualization skills, whereas the MRT and MCT are commonly used elsewhere. Some international research teams have used multiple instruments at universities in the US, Europe and Brazil, (Leopold et al., 2001; Medina et al., 1998), enabling general comparisons between the US and other countries.

In general, the average scores of the PSVT-R are consistently reported to be around 75% across US four-year engineering universities; many other studies report similar data but have not been included here for the sake of brevity. The notable exceptions discovered in this investigation are Virginia State University, a university that historically enrolled formerly disadvantaged students (49%) and Essex County College, a two-year community college with a pre-engineering program (64%).

Average scores for the MRT are comparable for universities in the US, Poland and Germany, with slightly higher scores in Brazil and Malaysia, and lower scores in Spain. The results from the study by Geary (2001) were based on a general population of students (non-engineering), and thus the average scores are lower, but suggest that the populations in the US and China are comparable in visualization skills.

Results of the MCT test are comparable with an average around 60% for universities in the US, Australia and Europe; the lower scores for the EEM in Brazil may be due to the fact that the researchers did not use the CEEB MCT but a "similar" instrument (Medina et al., 1998). These results are reported here in order to demonstrate gender differences.

Gender differences comprise another significant factor in these studies. Although not reported here, many of the studies cited in Table 1 focused on gender differences and showed a

School or Country	n	Test	Avg. Score %	Source/Comments
MTU	300/65	PSVT-R	80.6*/69.7†	Sorby & Baartmans, 1985
MTU	98	PSVT-R	76.2	Sorby, 1997
MTU	247	PSVT-R	50.5ß	Sorby, 2001
WCU	31	PSVT-R	73.3	Ferguson, 2008
NCSU	249	PSVT-R	74.5	Branoff & Connolly, 2008
Purdue	69	PSVT-R	80.9	
US 8th grade	37	PSVT-R	64.3	Parolini, 2006 middle sch. hon.
EssexCC	102	PSVT-R	64.1	Yue, 2006
Indiana	203	PSVT-R	64.5	Hake, 1995 Physics/premed
VSU	55	PSVT-R	48.7	Study, 2006
Cracow	484	MRT	65	Gorska, 2008
Sao Paulo	605	MRT	70	Seabra, 2008
UKL	220	MRT	63.3	Leopold, 2001
Cracow	196	MRT	61.4	
MTU	55	MRT	61.3	
Spain		MRT	41.3	Martin-Dorta, 2008
Malaysia	138	MRT	~70	Rafi, 2006
UMC	66	MRT	38.4	Geary, 2001 non-engineering
Shanghai	40	MRT	39.2	
Cracow	360	MCT	60	Gorska, 2008
Monash	91	MCT	64.5	Field, 1999
UKL	220	MCT	63.7	Leopold, 2001
Cracow	198	MCT	59.8	
MTU	57	MCT	57.6	
Szent Istvan U		MCT	57.7	Nemeth, 2007 (Hungary)
EEM Brazil		m-MCT	32.3*/26.2†	Medina (1998)
MTU		MCT	54.3*/37.5†	

Table 1. International Comparison of Spatial Skills of Engineering Students
* male students
† female students
ß students in remedial course (below 60% on pre-test)

significantly lower average score for females when compared to males. In an internet-based study of individuals in 40 countries (Silverman, 2007), females exhibited significantly lower scores than males on mental rotation tests across all ethnic groups; note that South Africa was the only African country included in this study. Much of this work has been focused on the debate regarding the source of these gender differences as genetic, environmental, cultural, or compound effects. Further discussion of gender-based differences are ongoing within the engineering graphics community, but are beyond the scope of this paper.

ENHANCEMENT OF VISUALIZATION SKILLS

Sorby has shown that spatial visualization skills are a strong predictor of success in engineering (2001). Thus, engineering educators have devised a variety of approaches to improve the 3-D visualization skills of engineering students. In general, these methods involve increased sketching of 3-D objects, use of manipulatives (3D objects), computer graphics animations of rotating 3D objects. The reader is referred to the literature for details (Ardebili, 2006; Crown, 2001; Ferguson et al., 2008; Holliday-Darr et al., 2003; Olkun, 2003; Onyancha et al., 2007, 2009; Sutton, 2007; Study, 2006; Williams, 2007).

Starting in the late 1980s, Sorby and Baartmans developed a remedial course to improve the spatial skills of students at Michigan Technological University (MTU). Students scoring below 60% on the PSVT-R were shown to have difficulty in their first engineering graphics course, and were thus encouraged to take the remedial course prior to attempting a graphics course. From 1993-1998, Sorby reported an average PSVT-R pre-test score of 50.9%, post-test score of 77% for 186 students in the remedial course (2007). These efforts led to the publication of a text and workbook (Sorby et al., 2003). The workbook includes these modules:

1. Isometric Sketching
2. Orthographic Projection: Normal Surfaces
3. Flat Patterns
4. Rotation of Objects about a Single Axis
5. Rotation of Objects about Two or More Axes
6. Object Reflections and Symmetry
7. Cutting Planes and Cross Sections
8. Surfaces and Solids of Revolution
9. Combining Solids

Results from MTU were reported for students in an updated course that utilizes visualization software in addition to the MTU workbook exercises (pre-test 51.3%, post-test 77.8%, n=50; Hamlin et al., 2008). The gains in post-test scores show an improvement in spatial skills up to a level comparable with the overall average scores of incoming students.

Further work has been done at Penn State Erie, The Behrend College, on the development of software to enhance visualization skills (Blasko et al., 2004). The VIZ website contains the following tasks: 1) Mental Rotations, 2) Water Level, 3) Paper Folding, and 4) Spatial memory: Rotating Letters.

These highly successful teaching materials have been combined and adopted for testing at seven universities in the US through the EnViSIONS project. In addition to the workbook and software, instructors were also provided with PowerPoint presentations for each workbook module. Each university tested the software and workbook materials under a variety of conditions, with different cohorts of students. Details are discussed by Hamlin et al. (2009). Significant gains in spatial skills were measured in all cases.

METHODS

Four modules of the EnViSIONS curriculum were selected for implementation at the Polytechnic of Namibia in early 2009. These modules were incorporated into the first year engineering graphics course, which is taken by all entering engineering students in the bachelors program, including civil, electronic, electrical (power), mechanical and mining. The course includes topics in 2D manual drafting and descriptive geometry; these students are not exposed to CAD until later in the curriculum. The topics for the selected visualization modules were isometric applications (sketching, axes, coded plans), orthographic applications (projection, sketching, orthographic to isometric transformations), and rotation of objects (modules 1, 2, 4 and 5). Students were presented with the lectures, followed by an open computer lab when the students could use the software. Attendance was not taken in the computer lab, but students were strongly encouraged to complete the software exercises for each module prior to attempting the workbook exercises. Approximately half of the workbook exercises for each module were assigned and graded. The PSVT-R (Guay, 1977) was used as an assessment tool for both pre-test and post-test.

RESULTS

A total of forty-one (41) PoN students completed the pre-test, workbook exercises, and post-test. Test results are shown in Table 2. With the use of only four modules from the EnViSIONS project, students showed a gain of nearly 12% in test scores on the PSVT-R.

	Pre-Test	Post-Test
Max	29	29
Min	6	6
Mean	15.66	19.15
SD	5.77	5.8

Table 2. PSVT-R Results for PoN Students

Table 3 compares the results of pre- and post-tests for students at PoN with students at Purdue University, Virginia State University and Michigan Technological University. The Purdue students included 14 Engineering and Technology Teacher Education students from all years who were presented with four modules from the EnViSIONS program, including isometrics, orthographics, flat patterns and rotations; lectures and optional computer exercises were included. The group of minority students from Virginia State University were given five sketching assignments on missing lines/missing views, isometric to multi-view sketching and section/auxiliary views while concurrently enrolled in an engineering graphics /2D CAD course. The MTU data represent results from a semester-long remedial course offered in the mid-1990s.

School	Pre-Test (%)	Post-Test (%)	Source
PoN	52.2	63.8	
Purdue	66.7	80	Harris, 2009
VSU	52.2	74.7	Study, 2006
MTU	51	78	Sorby, 2007

Table 3. Comparison of PSVT-R scores for selected differing cohorts and interventions

Percent gains for the PoN students were significant but still below gains made by students from VSU and MTU. This is not surprising due to the limited exposure of the PoN students to the visualization curriculum as compared to the MTU students. Gains for the VSU students may also be higher due to concurrent exposure to 2D CAD; PoN students were concurrently enrolled in engineering graphics course which included some descriptive geometry but no CAD. Other factors that may have influenced these differences, such as emphasis on grading and optional software use may also be influential. Gains for the Purdue students were small, probably due to the "ceiling effect" of starting at a high level, and the broader backgrounds and previous graphics experiences of these students.

CONCLUSION

Spatial visualization skills of entering first year engineering students at the Polytechnic of Namibia are significantly lower than those of most students in industrialized countries, but comparable to cohorts of minority engineering students in the US. Based on studies of visualization skills within the general population in various ethnic groups, we hypothesize that these differences are due to factors of prior experience and educational background. With only limited exposure to a visualization curriculum, the PoN students exhibited significant improvement in visualization skills. Larger gains have been shown by students with similar pre-test scores but more exposure to various treatments including spatial skills development exercises and CAD instruction. We recommend that training in spatial skills be continued and expanded for entering PoN engineering students.

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