Exploring Spatial Ability and Mapping the Performance of Engineering Students

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***Abstract**: One of the more important aptitudes for students studying engineering courses is spatial ability. Spatial ability can be defined as the performance on tasks that require the mental rotation of objects, the skill to understand how objects appear from different perspectives, and the skill to conceptualize how objects relate to each other in space. This aptitude requires visual and perceptual abilities to interpret what is seen, and spatial understanding to mentally manipulate visual representations. Engineering students require these abilities to be effective designers but our understanding of spatial ability and its elements are not well understood. In many respects, spatial ability is not given the attention it deserves.*

Reported in this paper is research conducted as part of an Australian Learning and Teaching Council funded initiative and the findings of a comprehensive study of the spatial ability of engineering students. Central to the study was a 3D ability test consisting of twelve subtests representing various elements of spatial ability. The test was used to evaluate the performance of engineering students across a range of disciplines and institutions.

Introduction

The concept of spatial ability is a complex one, it does not relate to a single ability but rather a set of abilities. As Maier (1998) proposed five spatial factors and refers to these as the five elements of spatial intelligence. Each of these is briefly described below:

- *Spatial Perception.* "Spatial perception tests require the location of the horizontal or the vertical in spite of distracting information".
- *Visualization.* "Comprises the ability to visualise a configuration in which there is movement or displacement among (internal) parts of the configuration".
- *Mental Rotation.* "The ability to rapidly and accurately rotate a 2D or 3D-figure".
- *Space Relations.* "The ability to comprehend the spatial configuration of objects or parts of an object and their relation to each other".
- *Spatial Orientation.* "Spatial orientation is the ability to orient oneself physically or mentally in space. Therefore, the person's own spatial position is necessarily an essential part of the task" (Maier 1998, 70-71)

Engineers as designers would regularly utilise spatial abilities to assist in resolving problems and understanding drawings. What has been considered in the past is that spatial ability is an innate ability but research conducted at the University of Newcastle has started to increase our understanding of spatial ability and the effect that it can have on students' performance in courses which utilise spatial abilities, specifically design related courses (Williams A., Sutton K and Allen, R., 2008; Sorby, 2006). In this paper we report on the findings of a significant project, funded by Australian Learning and Teaching Council (ALTC), which measured the spatial abilities of a large number of Engineering students from a range of disciplines and considers their performance in the context of their disciplines as well as of other factors including University Admissions Index (UAI) and experience they have had with graphics based learning experiences. The results provide an interesting perspective of student spatial abilities.

Considering Spatial Ability

Understanding of spatial ability has increased and changed over recent years. It has become evident that a range of abilities exits relating to spatial ability rather than a singular ability it now believed that a more accurate measure of 3D understanding consists of a mixture of test types (subtests) rather than any one particular test. The majority of existing tests are generic measures and do not provide a precise prediction of an individuals' performance in real work situations (Sutton and Williams 2007). Also, traditionally, tests of spatial ability generally don't target specific disciplines, thus the work reported in this paper differs from past studies in that it reports on a discipline specific study.

In this study twelve subtests were developed and implemented, the results of 154 engineering students were compared across the twelve domains. The types of skills and their testing are displayed in the examples of test items drawn from the twelve subtests, shown in Appendix 1 (included at the end of the paper)

Results

The results of the study identified interesting outcomes across three aspects firstly to the overall performance of the engineering students and then consideration of their performance across the represented disciplines. The second aspect is that of the relationship of the UAI scores in relation to spatial ability performance. Finally the relationship of years of experience with technical drawing or design type activities and their implications for spatial ability is considered.

Overall Results of Engineers

In developing the subtests the level of performance of the students from the different disciplines was considered from previous trials (Williams A., Sutton K and Allen, R., 2008; Sutton and Williams 2007). The performance of students from design based disciplines was consistently higher across all measures Williams A., Sutton K and Allen, R., 2008). A primary issue was the importance of developing a series of tests which would discriminates across a range of disciplines. The current subtests do achieve this level of discrimination, trials showed students from non design disciplines perform at a significantly lower level. The overall performance of the engineers is shown in Figure 1, which shows the performance of the engineering participants across the twelve subtests (refer to Appendix 1 for the explanation of the subtests).

The results indicate that this group of first year students performed at different levels across the range of tests. The task performed at the lowest level was that of "true length" a significant majority of the students do not understand the concept of true length of lines or surfaces which is evidenced in the "Mental Cutting" subtest where students are required to visualise shapes resulting from cutting planes passing through objects. In fact the students' ability to consider objects which change in relation to the viewer is not strong. This is also evidenced in the lower performance in "Building Recognition and "3D Mental Rotation" these proving more difficult for the students.

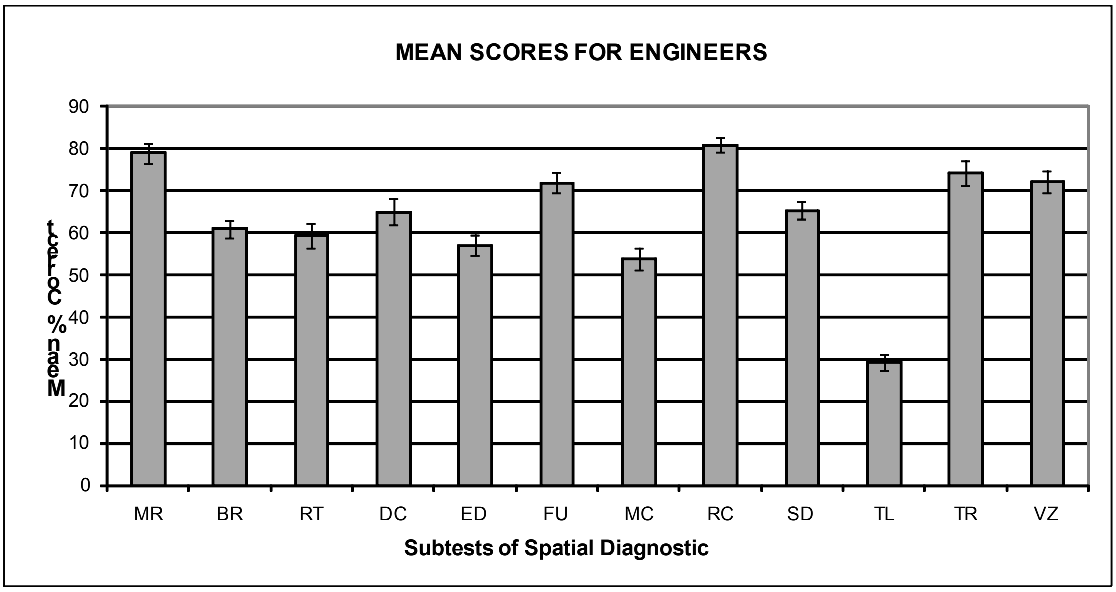


Figure 1: Results of the Engineering Group across the Twelve Subtests

Shown in Figure 2 are the overall results of the three Engineering disciplines which took part in the study. Although not of significance to the study it is interesting to note that there is a difference across the disciplines which may not have been expected. It will be of interest to see if this is continued when the test is conducted across the full range of disciplines and across a number of universities with a larger population.

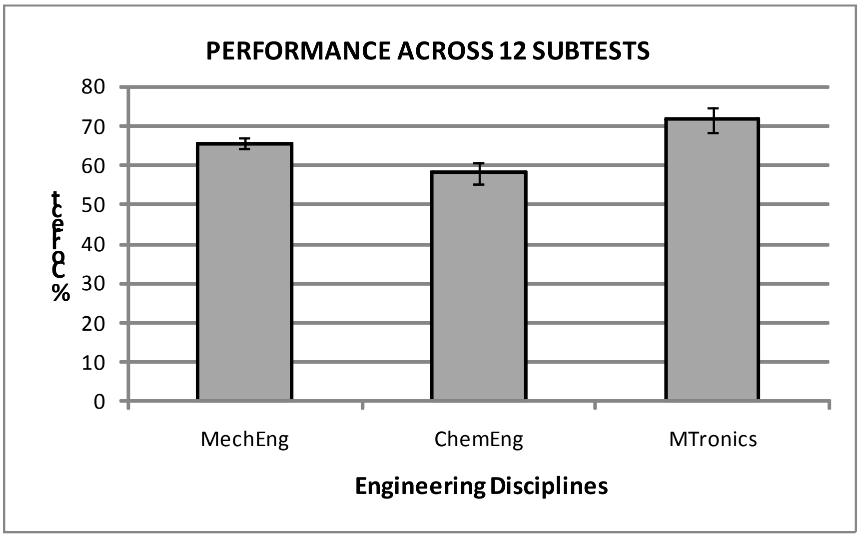


Figure 2: Overall Results across the Three Disciplines Studied

The Relationship of Spatial Ability to UAI

The relationship of UAI to performance in spatial ability provided some interesting outcomes as evidenced in Figure 3. The expectation by the project team would have been that there would be a positive relationship between the UAI performance and the spatial ability results but this proved wrong as there is a negative relationship. This makes us consider the potential problems which students entering with a high UAI might have in subjects utilising spatial abilities, often drawing and CAD courses are early in the curriculum structure of engineering programmes. Obviously further study is required in this domain but with such consistent results the question must be asked about preparedness for study in some types of subjects. One factor that may impact on this situation is the experience level of the students undertaking the tests.

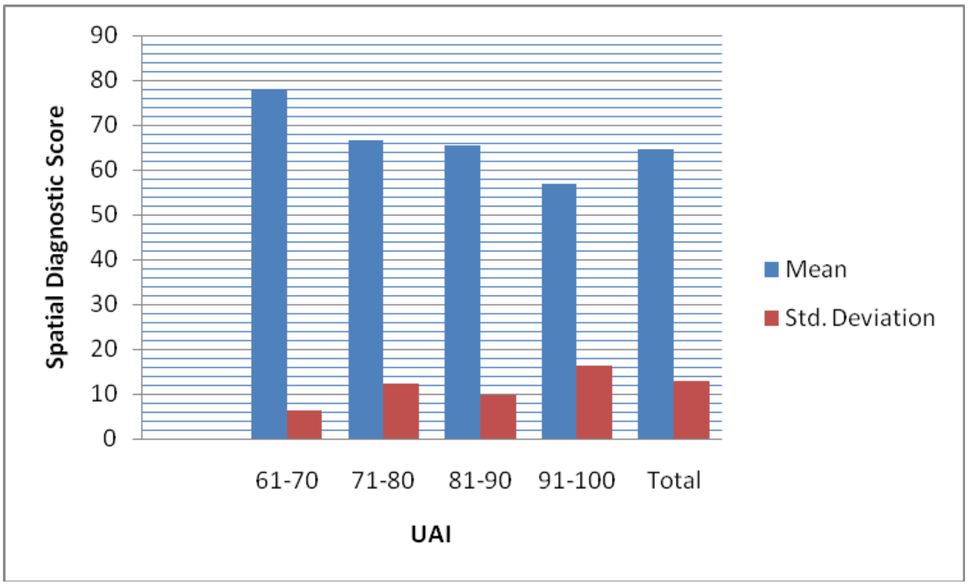


Figure 3: Results for spatial diagnostic shown in percentage terms.

Experience and Spatial Ability

What can be evidenced in the study, see Figure 4, is that students who have had experience with technical drawing or design subjects at school or have worked in these areas in industry perform better than those students with lower experience levels. The correlation is quite strong showing that the students who come into engineering may because of their secondary school experience have a disadvantage when confronting spatial ability related experiences.

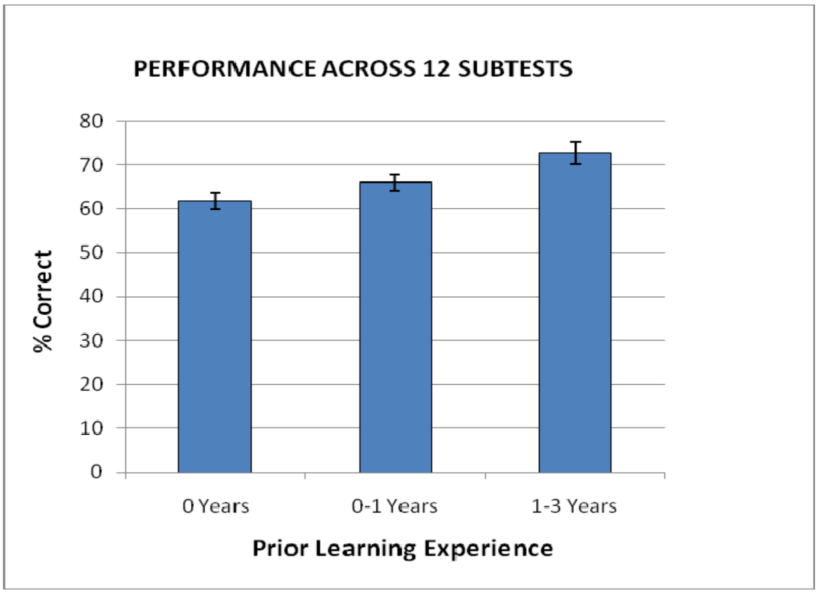


Figure 4: Impact of Experience on Spatial Ability Test Outcomes

Conclusion

What can be evidenced from the material reported from this study is that students do not perform equally as well or as could be expected across the full range of spatial ability tests which have been developed. The implications of this are that students may not relate well to subjects that utilise spatial ability. It is not possible to consider UAI as an indicator of expected performance when dealing with spatial ability problems as there is no relationship evidenced in this study.

What can be evidenced is that level of experience impacts on students' skill levels in spatial ability. What these findings indicate is a potential for spatial ability being improved through experience, achieved through the application of developed learning tasks that allow active exploration and participant interaction, thus emulating experience.

As with most research outcomes, one study identify further questions. In the coming year this project will be rolled out nationally and will be implemented in a large number of engineering programmes. With larger participant numbers and with more disciplines participating better comparative studies will be able to be conducted. Despite the questions that remain to be answered there is evidence from the study reported that there are issues concerning spatial ability, UAI is not a predictor but experience is.

What is becoming apparent is it may be necessary to engage the students in activities which involve spatial ability development as part of the core curriculum or even outside the core curriculum.

References

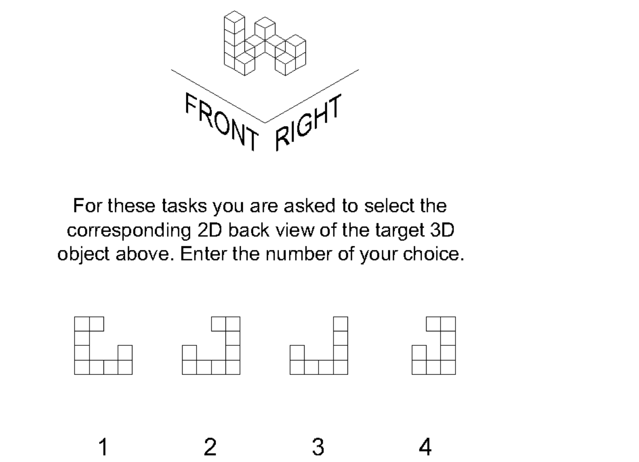
Maier, P. H. (1998). Spatial geometry and spatial ability: how to make solid gemetry solid? In E. Cohors-Fresenborg, K. Reiss, G. Toener & H. G. Weigand (Eds.), Selected papers from Annual Conference of Didactics of Mathematics 1996 (pp. 69-81): Osnabreck.

Sorby, S. (2006). Developing 3-D spatial skills for engineering students. Paper presented at the Australasian Association of Engineering Education Conference, Auckland University of Technology, New Zealand.

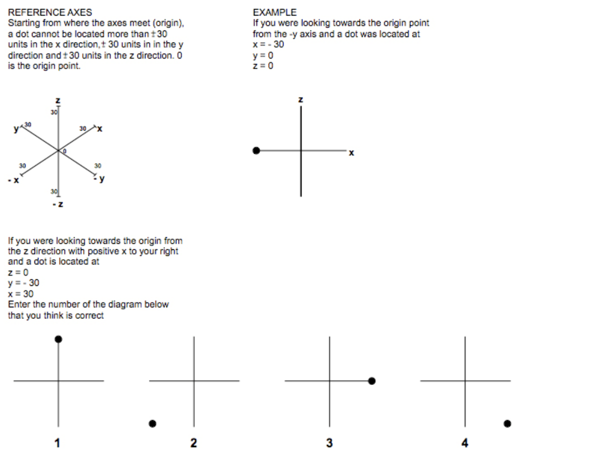
Sutton, K. J; Williams, A. P. (2007) Spatial Cognition and its Implications for Design. International Association of Societies of Design Research, Hong Kong, China (2007).

Williams Anthony Philip, Sutton Kenneth John, Allen Rebecca Jane, (2008)'Spatial ability: Issues associated with engineering and gender', Proceedings of the 19th Annual Conference for the Australasian Association for Engineering Education, Yeppoon, QLD

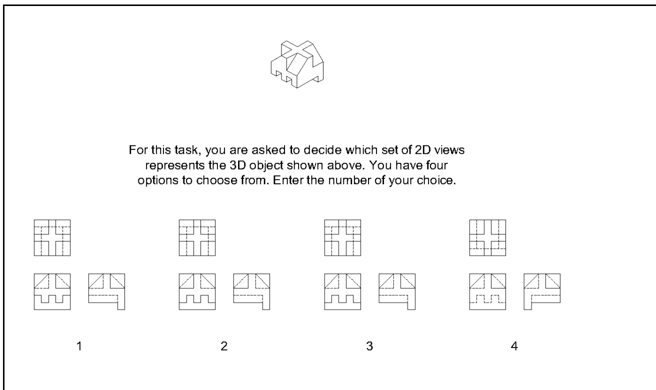
Appendix 1



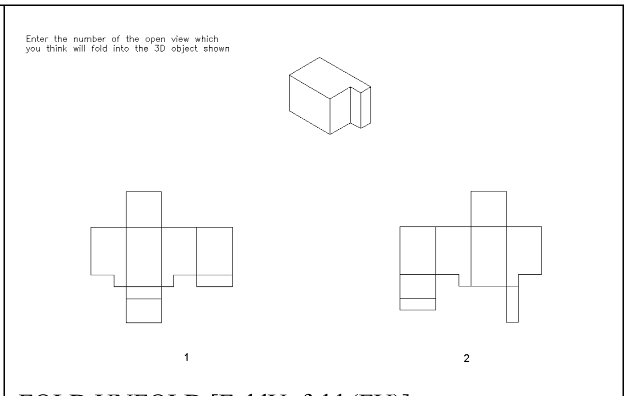
BUILDING RECOGNITION [BuildRep(BR)]



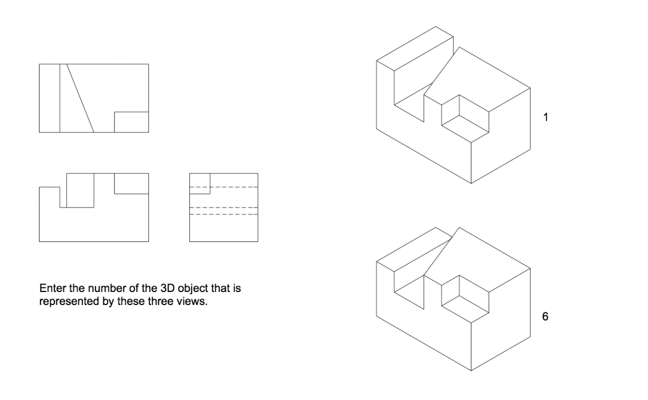
DOT COORDINATE [DotCoord (DC)]



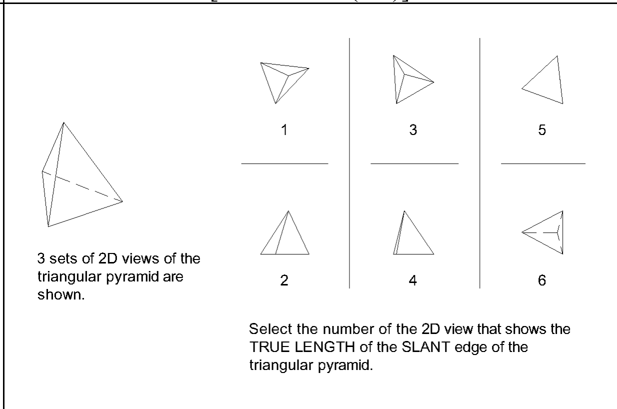
ENGINEERING DRAWING [EngDwg (ED)]



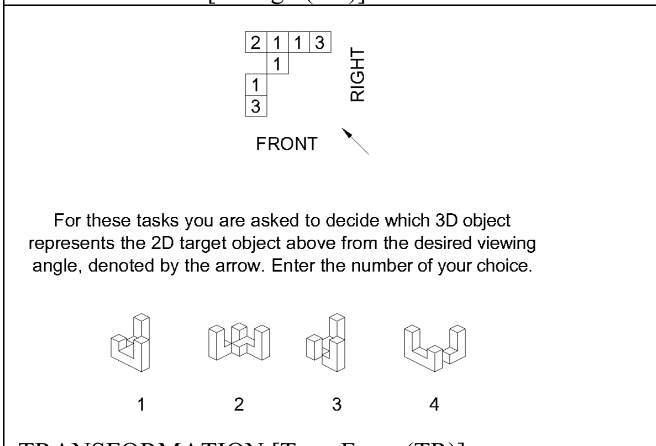
FOLD UNFOLD [FoldUnfold (FU)]



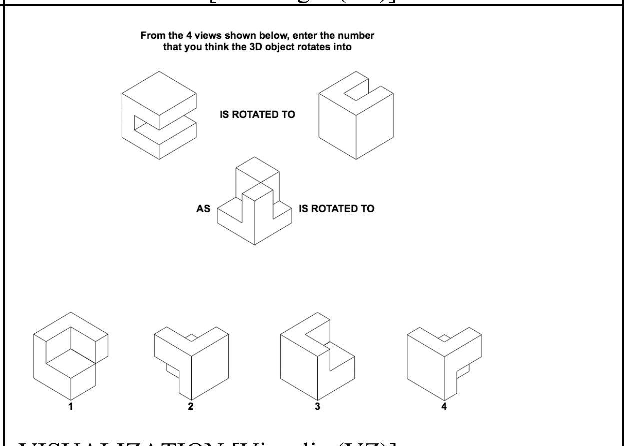
RECOGNITION [Recogn (RC)]



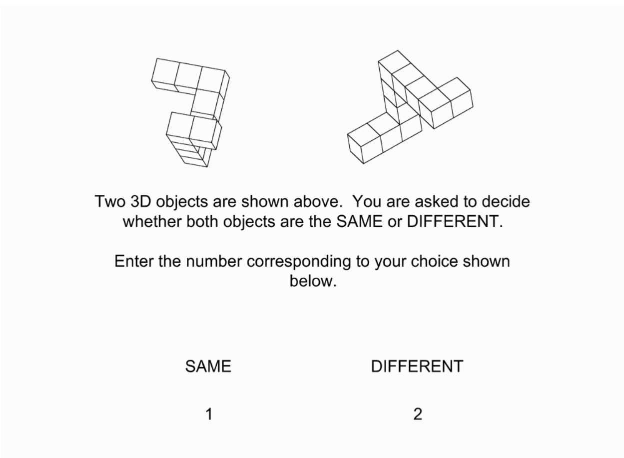
TRUE LENGTH [TrueLngth (TL)]



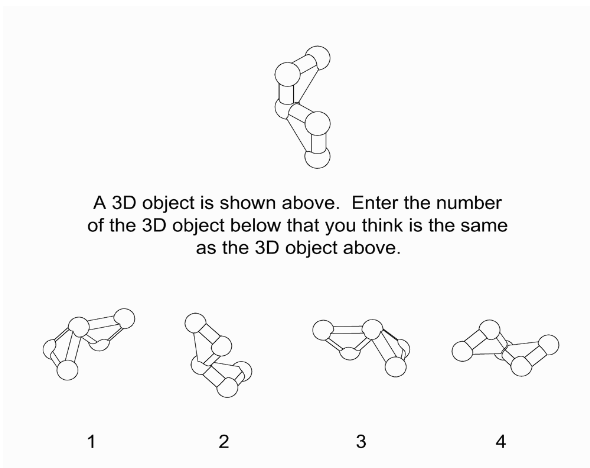
TRANSFORMATION [TransForm (TR)]



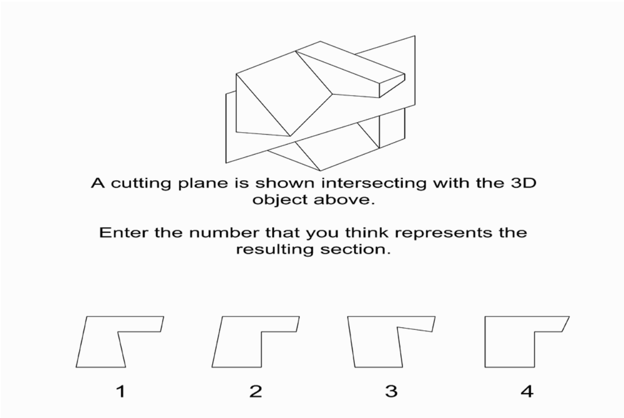
VISUALIZATION [Visualiz (VZ)]



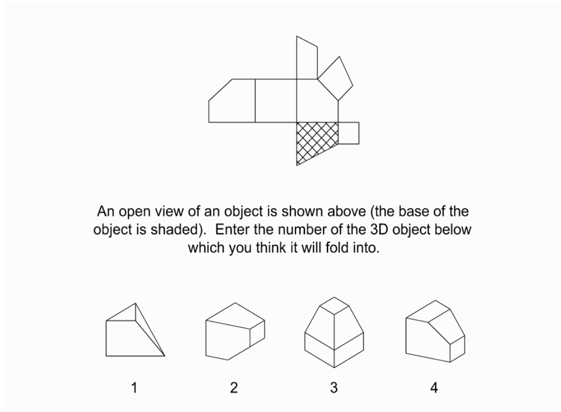
MENTAL ROTATION [MRotate (MR]



3D MENTAL ROTATION [3D Rotate (RT)]



MENTAL CUTTING [MentalCut (MC)]



SURFACE DEVELOPMENT [SurfDev (SD)]

Examples of the Twelve Subtests of Spatial Ability used in the Study

Acknowledgements

The authors would like to acknowledge the support that the Australian Learning and Teaching Council (ALTC) provided in funding this project.