Spatial Ability and its Implication for Novice Architecture Students

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ABSTRACT: Constructive perception ability that combines perception, conception and spatial reasoning composed of visual analysis, synthesis and representation in iterative nature can be argued to be equally related to creative design ability.

One of the more important aptitudes for students studying Architecture design is spatial ability, often referred to as simply visual perception. Spatial ability encompasses the mental manipulative skills required to perform mental processes such as the rotation of objects, the understanding of how objects appear in different positions, and the conceptualisation of how objects relate to each other in space. The relationship between various cognitive abilities and design creativity is a necessary consideration for Architecture education.

Spatial ability is a construct generally considered to comprise of several spatial factors called elements or components where each measures a separate spatial skill. Literature has reported that there is a relationship between the spatial ability of students and their success in certain types of subjects, e.g. technical drawing. However, there are not a large number studies that have focused on the relationship between spatial ability and design-based courses which are prevalent in the Architecture discipline.

This paper reports on a research project concerned with the assessment of spatial ability specific to design disciplines, Architecture being a primary design discipline studied. The project measured spatial performance using an online 3D ability test (3DAT) that was developed in accordance with psychometric test development procedures and properties such as reliability and validity for the 3DAT are above acceptable standards. The 3DAT measures choice accuracy and reaction times across a range of abilities that were expected to exist for design students. The spatial performance of students was compared to their results on a number of design projects in a first year design studio to establish if there was a positive relationship between their spatial ability and their performance in a course focused on design.

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INTRODUCTION

Design is a many-splendored activity: architects, engineers, graphic designers, industrial designers, interior designers, landscape designers, fashion designers, computer hardware and software designers (and many others) are all designers and they all produce a design which is the outcome of a design process (designing). A design is a representational form (eg, a drawing or diagram, a computer image, a model, a prototype), of the intended product (building, machine, garment, advertising image, electronic process, etc). The design is generally communicated to other people, providing details of its form and if necessary function. The design process (designing) leading to a design is essentially a set of thinking processes that are creative in particular ways. Sketching, modelling, experimenting, trial and error, etc, may also be part of a designing process, but they are supporting activities to the chain of thinking processes that are essential and central to any designing process. Architecture is foremost in its application of spatial abilities, a component of design cognition, to the creation of space.

Cross (2006): relates how design cognition—the ways that designers, think, work, and know is of fundamental importance to the design activity. Designers' behavioral and cognitive processes are unique, thus design can be separated from both scientific and artistic forms of knowledge, both of which have tended to engulf design within their own epistemological and pedagogical frameworks – need to establish own language and research of design – However, care needs to be taken not to reduce design into static cognitive and behavioral categories for the sake of it.

These themes provide us with an understanding of what architects and designers do, however they do not inform us about the Design Thinking which underpins such design practice. Cross (1995, 2006) suggests that design aptitude consist of several key components including the ability to resolve ill-defined problems, adopt solution-focused strategies, employ abductive, productive and appositional thinking, and use nonverbal, graphic/spatial modeling media.

This definition of design cognition acknowledges the particular ways that designers think, work and know. It separates designers' behavioral and cognitive processes from scientific and artistic forms of knowledge, both of

which have tended to engulf design within their own epistemological and pedagogical frameworks. The unique nature of design processes suggest that there is a need to establish a distinct language and research of design, though care needs to be taken so that design is not reduced to static cognitive and behavioral categories for the sake of it (Allison 2008; see also Snodgrass and Coyne 1992).

Architectural Education must be able to draw from our knowledge of cognition and inform the design of its programmes of study to best develop these abilities. As such an important component of design cognition is spatial abilities. Therefore it is important for us to consider the implications of these abilities on design and also the development of effective Architectural Education.

1. SPATIAL ABILITY

One of the more important cognitive components of the design process, especially for architects in their role as designers, is spatial ability. The concept of spatial ability refers to a complex process that designers utilize extensively during the design activity. Spatial ability has been defined as:

> the performance on tasks that require mental rotation of objects, the ability to understand how objects appear at different angles, and the ability to understand how objects relate to each other in space (Sutton & Williams 2007);
>
> "… the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimulus objects" (McGee, 1979, p. 893);
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> "… visual skills, spatial manipulation, recognizing the similarity of visual images, and imagining how visuals might appear in other orientations'' (Jonassen & Grabowski, 1993, p. 64);
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> "… the ability to generate, retain, and manipulate abstract visual images (Lohman, 1979, p 188)";
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> the ability to conceptualise links between reality and abstract; and the aptitude needed to mentally process three-dimensional images of objects (Fleisig et al. 2004).

Considered in their most basic form, spatial abilities form part of the visual thinking used in everyday life. Common activities, such as manoeuvring a car along an unfamiliar road or rearranging furniture, require visual thinking. Spatial ability requirements escalate when higher order skills are needed as, for example, in the interpretation of technical drawings such as in building plans and in the process of translating these plans into buildings (McKim, 1980; Lajoie 2003). High spatial ability is therefore a requirement for design related activities where it is related to successful performance in real-world occupations such as architecture (Cronbach, 1970; Smith, 1964).

Spatial Ability and Design Learning

Spatial ability in the domain of architectural design is essential for both learning and problem-solving, even when a problem is not specifically spatial (Alias et al. 2002). From this it can be easily deduced that spatial ability plays an important role in architectural education and for the learning experiences of architecture students. There is a body of research (Sutton & Williams 2007; Potter & van de Merwe 2001) that indicates the importance of spatial ability in graphics-based courses and the implication of poor skills on success rates and career choices. However, despite there being a vast amount of research on spatial ability, there is very little known about the effects of spatial ability on design thinking and how it is developed through appropriate education programs. Furthermore, previous research on spatial ability tends to focus on one or two test types and neglects test types that specifically target spatial cognition relevant to disciplines such as design (Allahyar & Hunt, 2003).

Spatial ability has in the past been considered an innate ability. Recent research conducted at the University of Newcastle (Sutton & Williams, 2007) has, however, started to increase our understanding of spatial ability as well as of the effect it can have on students' performance in architectural design courses. A substantial part of spatial ability is 3D understanding; that is, the ability to extract information about 3D properties from two-dimensional (2D) representations (Sutton, Heathcote, & Bore, 2005). For the purpose of interpreting 2D drawings that are based on a notational system, architecture students require the ability to think and reason in 3D. By adopting the 3D Ability Test (3DAT), the projects reported here aimed to measure the spatial ability of students.

The study on which this paper reports was conducted under classroom and laboratory conditions and in accordance with established psychological methodology protocols. The underlying hypothesis was that no one spatial task is ideal when measuring the spatial performance but rather multiple subtests are required in order to gain a measure spatial performance.

Testing Spatial Ability

3DAT is a computer-based instrument that measures choice accuracy and response time. In its present form, the 3DAT consists of 5 subtests. Each subtest aims to measure separate factors of spatial ability, often referred to as elements or spatial skills. The 3DAT is delivered online and can be used for research purposes or as a spatial diagnostic test. It consists of 30 items that are divided into 5 subtests. The test items are all made up of straight lines and flat planes, but they vary in form and are novel in design. Below is a description of the broad areas that define the subtests:

Mental Cutting: A 3D view of an object intersected by a cutting plane is presented (USA University entrance examination as cited in Sorby & Baartmans 2000). The idea is to identify the resulting 2D shape of the surface when the top portion of the object is removed. Participants choose from 4 options. This subtest identifies a spatial skill defined as Spatial Sections.

Building Representations: A 3D view of an object based on an arrangement of cubes is displayed with front and right views clearly labelled (Ben-Chaim et al., 1988). Participants are asked to identify the correct 2D back view of the object from 4 given options. This subtest identifies a spatial skill defined as Spatial Perception.

Transformation: A top view of an object in 2D format is presented and a viewing direction is provided as a reference point. The object is an arrangement of cubes with numbers in strategic positions to indicate the 3D shape of the object (Olkun, 2003). Participants decide from four 3D options which one matches the given viewing direction. This subtest identifies a spatial skill defined as Spatial Reasoning.

Mental Rotation: Participants decide if a rotated isometric projection of an object matches the isometric projection of a standard or its mirror image (Metzler & Shepard 1988). The object on the left is always in the same position and is the referent. The object on the right can be the same or the mirror image of the referent and its orientation in the XY plane can be different.

Dot Coordinate: Participants are shown an isometric projection of a 3D Cartesian coordinate system and a text description of the position of a point in that system (Bore & Munro 2002). From four orthogonal projections, participants choose the projection that corresponds to the description. This subtest identifies a spatial skill defined as Spatial Orientation.

The 5 subests cover a comprehensive range of different factors of the spatial ability construct and provide a detailed understanding of the spatial ability of participants.

WHAT WE HAVE LEARNED

As has been stated above, there is not a significant understanding of the role of or the significance of spatial ability in architectural education. There have been studies into the significance of success of engineering students (Sorby 2005) but as yet there is not a similar body of knowledge concerning its role in architectural education. Following are results from the initial phase of a long term study into the implications an architecture student's spatial ability has on their success in the study of architecture which in turn effects the quality of architecture graduates. To achieve this understanding during 2010 all students enrolled in the first year of their program of study in the School of Architecture and Built Environment at the University of Newcastle were encouraged to undertake the 3DAT during their Communications courses, three times during the year, week one of Semester one, week one of Semester two and the final week of semester 2, week 13. This sequence of tests captured the students' spatial ability score across the academic year at the beginning, half-way and the end of the year. There were other cohorts of students in the group but for study reported in this paper is for first year Architecture students and for the purpose of comparison or contextualisation the first year Construction Management students were also tested. The study, of these students' spatial ability attributes has yielded a range of interesting and, in some cases significant, results. The details of the findings are documented below.

Performance of the Architecture students

The 3DAT test, applied in this study, involved 30 questions across the five areas, six questions each, identified above. Students in the Architecture cohort performed well the mean results for the cohort being shown in Fig. 1, below. It is important to note that the architecture students' scores were higher than equivalent level students from non-design based programmes of study (Sutton & Williams 2007). Importantly the results indicate an improvement of spatial ability performance across the year but most notably during semester 1. The improvement during the year occurs because of the student engagement with the range of learning experiences in graphics and design activities associated with the study of architecture, specifically students undertake design studio each semester as well as communication courses which provide both freehand, drafting and CAD learning experiences.

What is evident in the results is that the students improved their score more significantly during the first semester rather than the second. The reasons that could contribute this would be very difficult to determine, without further studies requiring a comprehensive analysis of the learning experiences of the students across the year. A simple evaluation of the curriculum shows that the only significant difference in the types of learning experiences was that in the first semester students did freehand drawing and drafting whereas in the second semester they undertake CAD. To undertake a thorough analysis of experiences is something that we may undertake in the future but it is interesting to consider the implications of freehand versus CAD and the relationship to the development of spatial understanding.

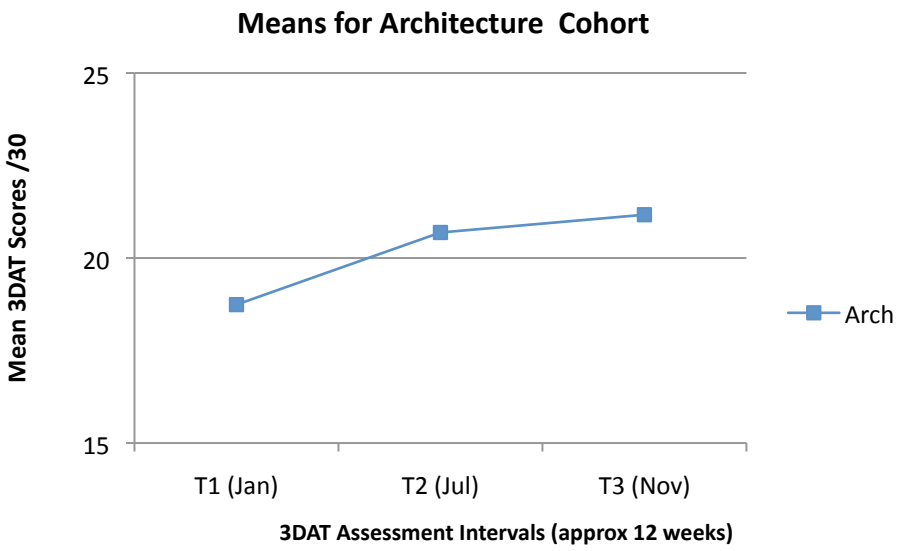

Figure 1: Architecture cohort result

Architecture and Construction Management

The performance of the more design focussed Architecture students compared to the less design focussed Construction Management, see Fig. 2 below, students shows outcomes that may be expected, the Architects performing at a considerably higher level, this specifically being the case across the year. The performance at the start of the year is quite different but as the year progresses the Architecture students improve whereas the Construction students remain static. Of interest is that the students undertake the same communications courses and the small amount of improvement in performance does occur in the first semester, again during the sketching and hand drawing course but do not improve during their CAD learning experiences. What is significant from the perspective of the Architecture learning experience is that their spatial ability does improve and this would relate to learning experiences where they are involved in solving problems that require spatial abilities.

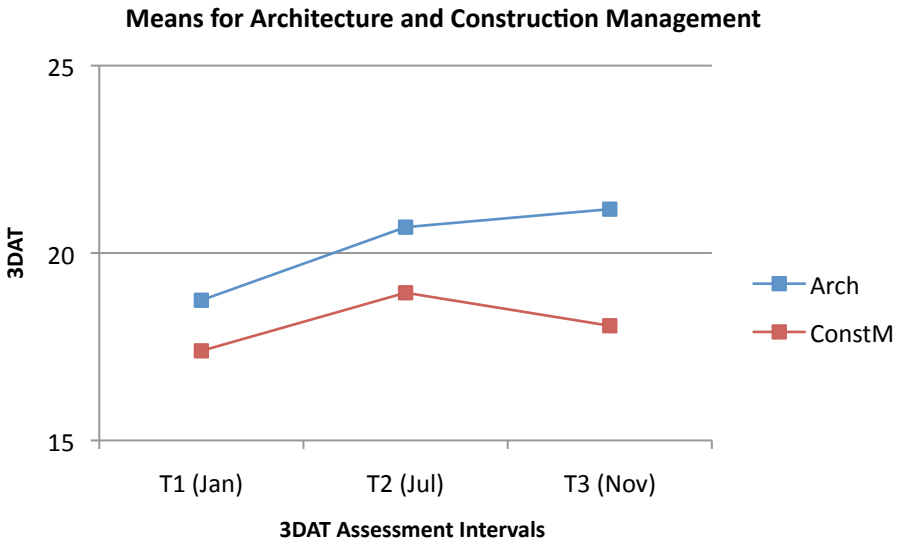

Figure 2, Means for Architecture and Construction Management students

The Relationship of Student ATAR score and Spatial Ability

One of the long held beliefs of universities is that high entry scores will ensure the quality of the students. Accordingly, it may be anticipated that there is a correlation between the novice designers' scores in spatial ability and their university entrance score, this having a historical link with the inclusion of spatial ability type problems in traditional IQ tests. It is, however, evident from the scatterplot shown (Figure 3) and the results presented in Table 1 that there is negligible correlation between university entry scores and spatial ability. The ATAR v 3DAT results are for Architecture students only. Three ranges of ATAR scores were used (71-80, 81-90 & 91-100). Correlation is shown for ATAR vs 3DAT for the first of three times the 3DAT was conducted Table 1 indicates that correlation was not significant.

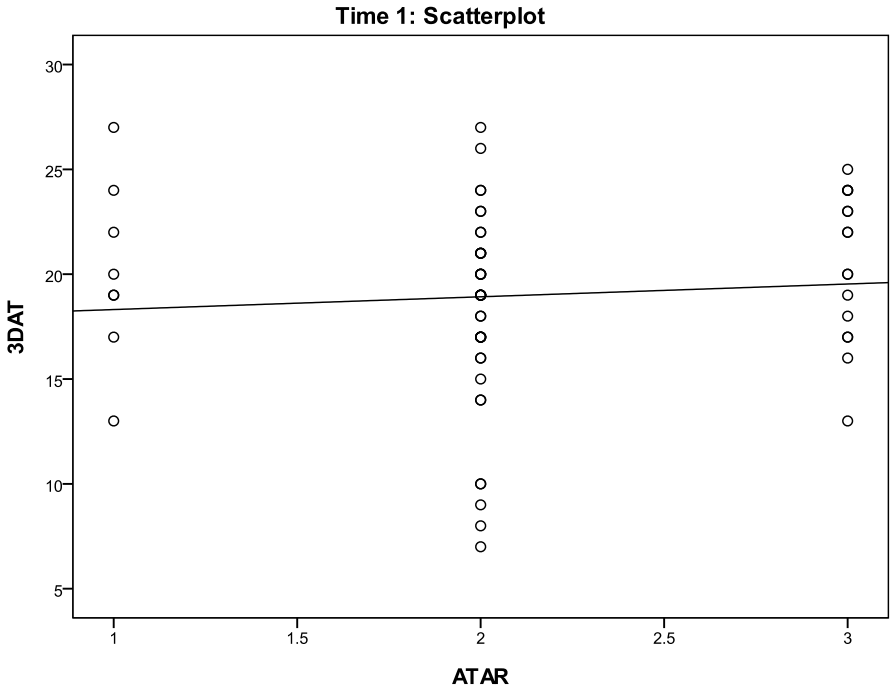

Figure 3: Scatterplot Showing ATAR and 3DAT relationship for Architecture Students

Correlation for Architecture ATAR vs 3DAT

			3DAT	ATAR
Time 1	3DAT	Pearson Correlation	1	.084
		Sig (2-tailed)		.515
		N	63	63
	ATAR	Pearson Correlation	.084	1
		Sig (2-tailed)	.515	
		N	63	63

Table 1: Correlation Coefficient for ATAR vs 3DAT for Architecture Students

The lack of significance would indicate that there is not a relationship between entry level of a students and their spatial ability. An examination of the Fig. 3, indicates that a student with a high ATAR is just as likely to have a low spatial ability score as a student with a lower ATAR. Therefore when it comes to ability in courses that require spatial abilities it is important to realise that in any class there will be a range of abilities and students may need support in enhancing their spatial skills.

Does Gender Make a Difference?

Traditionally there has been a difference in the spatial ability scores between males and females with males scoring higher results in tests (Sutton & Williams 2007). Over the past 4 years the authors have noticed a trend in the scores when comparing gender, specifically the difference has reduced. In the tests being reported in this paper it was apparent for the first time that the females were statistically equal to the males. Interestingly it was during the learning experiences in the architecture programme that the females showed a higher outcome that their male peers over the year, see Figure 4 below which shows the architecture and construction management cohorts combined. Noteworthy is that a significant gender difference was not found for T1, T2 or T3. For both males and females considered separately, there is a significant improvement T1 to T2 and T2 to T3, but not for T2 to T3. However, the practice effect would need to be deducted to be certain that any real learning has occurred in the classroom as a result of the learning experiences. Looking at the figure below, females appear to have benefited more from their learning experiences than males.

The reasons for the change in the difference between the genders scores over recent years is most likely attributed to the primary and secondary school curricula being more consistent between gender than has been the case in past years, especially where females are required to undertake technical drawing type subjects at school in the Design

and Technology subjects. Also anecdotally the use of computer games and simulation programmes may have also contributed to the elimination of the difference in spatial ability scores achieved.

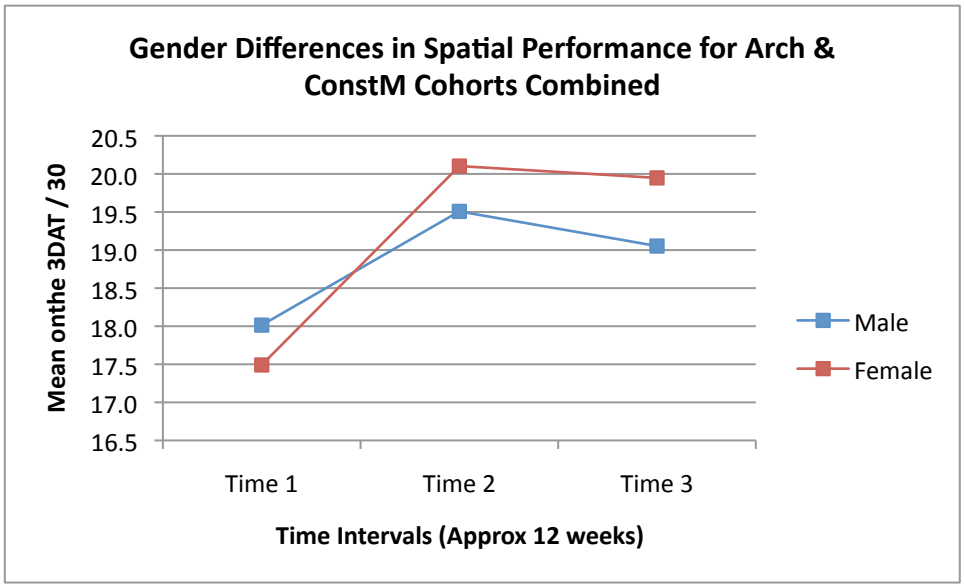

Figure 4: Gender Differences across Three Implementations of the 3DAT

CONCLUSION

What has been evident over the years that the studies have been conducted using the 3DAT to measure the students in a range of university programmes is that there is a relationship between students who chose design based courses and their spatial ability. What has changed over the period of testing is the difference between the results achieved by the female students. Most recent tests indicate that the once expected difference between the performances of the genders has dissipated to a point where there is not expected difference between the spatial ability of females entering the architecture programme.

What the most recent studies which were applied to architecture students have shown is that the architecture students do improve their spatial ability over the period of their first year of study at university. Although further testing is required there is an interesting outcome shown in the difference achieved by students after sketching and hand drawing as compared to CAD. Further study will indicate if it is the specific activities done during the hand drawing which contribute to the improvements or if it is the physical nature of the experiences. Also to be considered in this situation is the different roles of the “drawing activities” CAD is predominantly used for documentation of design ideas where freehand drawing is more likely to be used during the creative design process.

What is evident from the study’s findings is that students who undertake architecture studies enter the programme with a diversity of spatial ability. Regardless of the students entry ATAR score spatial ability is independent of the academic performance of students. It should be considered that when preparing learning experiences, even for perceived bright students, it must be acknowledged that some students may have difficulty with problems which involve complex spatial concepts or spatial manipulation based questions. It is important that students are exposed to drawing type courses which will allow them to enhance their entry capability levels.

Considerations for future studies are the need to better understand the relationship between spatial ability scores and student performance in design courses. This will be able to be achieved through correlation of student outcomes from design studios which involve extensive design activities. Also further study needs to be considered so as to better understand the specific type of activities which will enhance students’ spatial abilities.

The study reported in this paper has begun the process to better understand the spatial skill presentation of students enrolling in architecture. It provides the basis for further analysis and assessment of students to better understand the implications of spatial ability of architectural learning experiences.

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