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Framing Spatial Cognition: Establishing a Research Agenda

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Abstract

A significant aim of research concerning human intelligence is to develop a comprehensive cognitive map of the human intelligence structure. The evolution of this knowledge base is mirrored through the chronological development of models which frame cognitive domains. The domain of Visual Processing (Gv), commonly known as spatial ability, is a domain which has seen significant advances in the pertinent knowledge base. Models framing this cognitive structure are arguably under-evolved through a lack of representation of factors identified in contemporary research. This paper presents the initial conception of a more comprehensive theoretical framework which builds upon existing theory. It is envisioned that such a framework could support further research exploring the nature of thinking in graphics and other related disciplines. A research agenda is discussed concerning the validation of this framework and its utilization in the holistic assessment of spatial ability.

Introduction

Previous research has comprehensively established the significance of spatial ability in a number of fields. For example, Harle and Towns (2010) note its significance within Chemistry, Lubinski's (2010) longitudinal study illustrates its significance across a variety of STEM disciplines such as Maths and Engineering and Sorby (2009) illustrates significant correlations between spatial ability and a number of introductory engineering, maths and science courses. Graphics and graphical education is another field where attaining a high spatial capacity is often cited as being advantageous (Sorby, 1999) and this link is supported by results from variety of correlational studies (e.g. Kelly Jr, Branoff, & Clark, 2014). The conception of a visualizing faculty was borne through research investigating the nature of peoples thinking, where a high capacity to visualize was recognized as a substantial tool supporting advanced numerical and graphical reasoning (Galton, 1879). Within the pertinent literature a multiplicity of research avenues have been established resulting in spatial ability being discussed through a variety of lenses. The rationale for exploring a variety of spatial factors stems from the agenda aiming to better understand the nature of peoples thinking and how this thinking can be operationalized in problem solving. For example, Hegarty and Waller (2004) discuss the discrimination between the spatial factors of mental rotation and perspective taking which is a critical avenue within graphical education due to the results of the previously discussed correlational studies. Burton and Fogarty

(2003) empirically describe the cognitive structure of imagery factors and it has been posited that the capacity to produce vivid mental imagery is pertinent to solving geometric problems (Schneider & McGrew, 2012). These avenues illustrate the complex nature of this cognitive domain. With such complexity, and the significance of this domain to graphical reasoning, the need for an underpinning theoretical framework has emerged (Harle & Towns, 2010) coinciding with the need to understand the characteristics of individual spatial factors (Kelly Jr et al., 2014). This paper presents an initial conception of a spatial ability framework, discussing a research agenda concentrating on its validation and presents a strategy for the utilization of the framework in the holistic assessment of spatial ability.

The Development of the Spatial Ability Framework

Since the conception of spatial ability it has been recognized as a cognitive domain inclusive of a variety of unique factors (Galton, 1879). Over time a variety of factors have been empirically uncovered and a significant amount is now known about the many areas of spatial cognition. The generation of such a vast body of knowledge in a relatively short time period has resulted in contention regarding the identification and classification of spatial factors and in the evolution of many related misconceptions (Carroll, 1993). Seery, Buckley and Delahunty (2015) discuss this issue noting how the concept of spatial ability itself is ambiguous within the literature. Through a systematic literature review they identify prominent definitions of spatial ability. These include Lohman's (1979) definition as *"the ability to generate, retain, and manipulate abstract visual images"* (p.126), Gaughran's (2002) definition as *"the ability to visualise, manipulate and interrelate real or imaginary configurations in space"* and Sorby's (1999, p.21) definition as the *"innate ability to visualize that a person has before any formal training has occurred"*. They further discriminate spatial ability from spatial factors, spatial skills and spatial aptitude.

A number of theoretical frameworks have been developed which describe the structure of human intellect and are inclusive of a cognitive domain relating to space (e.g. Schneider & McGrew, 2012; Thurstone, 1938; Vernon, 1950). The Cattell-Horn-Carroll (CHC) theory (Schneider & McGrew, 2012) is arguably the most comprehensive of these frameworks and culminates a large body of human intelligence research into a framework inclusive of a domain of Visual Processing (Gv), otherwise known as spatial ability. However as noted by Carroll (1993), (one of the main contributors to the theory), there is significant potential for more factors to exist within the domain. One reason presented for this is the historical inability to test posited dynamic factors due to technological constraints. This view is echoed by Schneider and McGrew (2012) in their welcoming of research focusing on the expansion of the domain.

Seery et al.'s (2015) literature review uncovered four core considerations which merit recognition in the development of a theoretical spatial ability framework. These include ensuring the uniqueness of each factor, ensuring the clear classification of factors, ensuring that the factors are generic such that prior semantic knowledge will not load on them and recognizing the difference between static and dynamic stimuli. The result of this work has served as a foundation for subsequent analysis of factors posited within the pertinent literature in conceptualizing an initial framework (Figure 1). While it is beyond the remit of this paper to present references for all analysed factors, a systematic chronological review of spatial factor literature was conducted beginning from the initial conception of the domain (Galton, 1879) where each posited factor was analysed against the criteria presented by Seery *et al.* (2015).

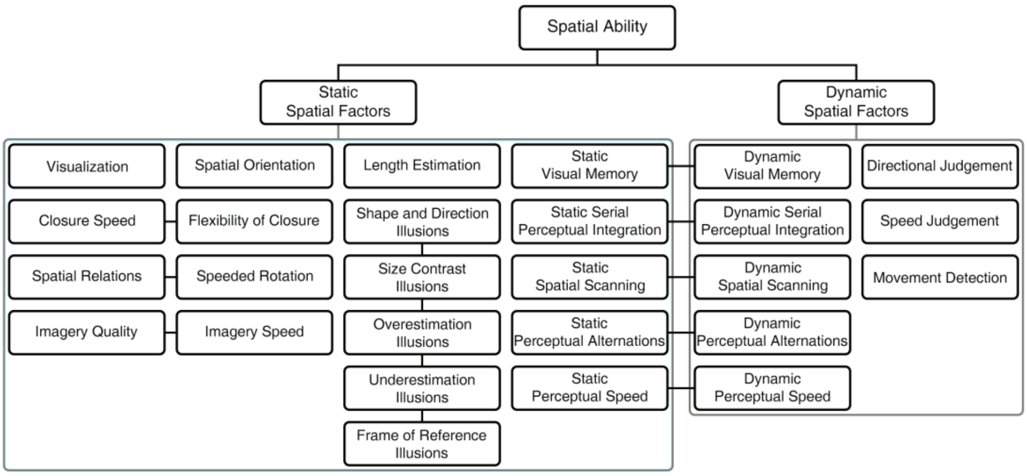

Figure 1: Conceptual spatial ability framework

The Research Agenda and Developing of a new Approach to Measuring Spatial Ability

The framework (Figure 1) has not yet been validated. The core methods adopted for identifying cognitive factors within this domain are exploratory and confirmatory factor analysis and while many factor analytic studies have been conducted which resulted in the identification of factors in the above framework, no study exists which is inclusive of all the identified factors. While many of the included factors are well supported within the literature and significant empirical evidence supports this, some factors may not exist and may instead be representative of one of the other well established factors. As such, a research agenda is proposed which targets the qualification and validation of the presented framework.

The significance of this agenda is illustrated through its existence as a research focus of the newly established National Spatial Skills Research Network (NSSRN) in Ireland (NSSRN, 2015). Under one of the networks active projects there are currently four studies being conducted concerning the qualification of the existence of factors within the framework. These studies are aimed at developing valid psychometric tests capable of discerning the existence of the less well supported factors and establishing if varying the nature of the stimulus between static and dynamic changes the nature of the cognitive activity adopted in spatial reasoning episodes. The results of these studies will provide the necessary results to empirically underpin each of the included factors with the next phase of the project being to gather a suitably large dataset capable of qualifying the entire framework. The overall aim of the project is to develop a strategy to comprehensively measure an individual's level of spatial ability. The project has resulted in the conceptualization of a strategy involving the generation of a person's spatial profile, a measure of a person's capacity within each spatial factor, through the conduction of psychometric tests which validly measure each unique spatial factor.

Conclusion

It is envisioned that identifying a person's capacity within each of the spatial factors may aid in identifying the causation underpinning the correlation between spatial ability and graphical competency through the provision of insight into the nature of graphical thinking and problem solving. As many of the correlational studies discussed earlier have identified factors pertinent to mental rotation and mental cutting as being substantially important, viewing spatial ability through a more holistic lens could identify a broader selection of important factors. Spatial profiles afford the potential to determine if specific groups of factors are important within specific contexts and an understanding of these groups may suggest distinct types of thinking.

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