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An exploratory study of students' approaches to generating, maintaining and communicating visual-mental images

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An exploratory study of students' approaches to generating, maintaining and communicating visual-mental images

The ability to synthesise and manipulate graphical information is a core cognitive aptitude. Visual-mental images are crucial to problem solving and design processes. The ability to manipulate and communicate perceptual and conceptual information graphically often leads to creative discovery and aids mental synthesis. Graphical education in Ireland supports the development of these 'concept driven competencies' through the study of plane and descriptive geometry and through engagement with design problems [1].

Previous research by Delahunty et al. [2] has highlighted a worrying issue of mechanistic conditioning within graphical education in Ireland. This conditioning may be occurring within the teaching and learning process as a result of external influences such as examination requirements. The effects of such conditioning may restrict students' ability to utilise a wider variety of visuospatial processes such as the ability to build and represent visual-mental images, which are critical for creative problem solving and design solutions.

This research study employed an exploratory case study approach where students participating in a graphical education module at the University of Limerick were tasked with building and representing visual-mental images. The task involved the building of mental images of regular geometrical configurations and subsequently communicating these by means of graphical sketches. Solutions were collected and analysed with the objective of determining the existence of any anomalies in the communicated mental image and in the cognitive process of generating and maintaining the image.

Analysis of the qualitative data highlighted a number of interesting findings. The geometric configurations, which students were required to observe and then build a visual-mental image of, were originally presented to participants in a random orientation. However, the solutions presented by the majority of participants, were communicated using standard engineering projection systems such as isometric, dimetric and trimetric projection.

The findings illustrate a possible conditioned approach to building and representing visual-mental images. This conditioning may have the overall effect of militating against students' ability to synthesise, manipulate and communicate both perceptual and conceptual graphical information. These findings raise a number of questions relating to the style of cognitive activity that students are engaging in as part of contemporary graphical education.

Introduction and Context

Contemporary graphical education at the University of Limerick incorporates significant levels of conceptual design activities as part of the four-year degree course. The generation and manipulation of visual-mental imagery has been shown to be an important cognitive skill during the development and refinement of design solutions [3]. Graphical education in Ireland supports the development of these *concept driven competencies* through the study of plane and descriptive geometry and through engagement with conceptual design problems [1].

The research presented in this study sets out to further explore the processes involved in building and manipulating visual-mental imagery. This current work is housed in the context of graphical education and particularly examines the role of working memory as a key component in visuospatial reasoning. The study builds on previous work by Lane et al. [4] who examined the role of the visuospatial sketchpad component of working memory in the context of developing sketching expertise. The findings presented in this study highlighted the large variety of cognitive strategies utilised in the process of forming and communicating a mental configuration and the existence of a possible conditioned approach to representing the geometric configurations [4].

Previous research by Delahunty et al. [2] has highlighted issues of conditioned mechanistic approaches to problem solving within graphical education in Ireland. The results of such conditioning may restrict students' ability to utilise a wider variety of visuospatial processes such as the ability to fluidly build and represent visual-mental images, which are critical for creative problem solving and design solutions. The focus of this study will be on this particular issue of conditioned approaches to visuospatial cognition. More specifically the primary focus was to further investigate the possible existence of deficiencies within the process of generating, maintaining and communicating visual-mental images within working memory.

The next section presents a short overview of the pertinent literature on memory systems and in particular visuospatial working memory as it relates to reasoning within graphics.

The Nature of Visual-Mental Imagery

Visual images are a distinctive type of mental representation and are unique in the sense that they *"depict"* rather than *"describe"* information [5]. Descriptions are generally *"amodal"* whereas depictions are *"modal"* and are in other words tied to some sensory modality such as vision [6]. Visual images are realised in the *"mind's eye"* and maintain spatial attributes such as structure in a two or three-dimensional spatial medium [6, 7].

Visual imagery plays a key role in creative problem solving and reasoning tasks. The dynamic nature of a visual mental image allows for manipulation, such as mental rotation and zooming [8], and consequently the development of multiple construals. Finke et al. [3] have shown through a number of experiments how the synthesis of visual images can lead to creative discoveries not possible in other modalities. Visual-mental imagery, when utilised in a task such as design, is controlled and processed within working memory and more specifically within visuospatial working memory [9].

Visuospatial Working Memory

Memory is defined as a "cognitive process which enables past experiences to be recalled" [10]. Within the cognitive focused literature there exists a general distinction between two types of memory systems within the human neural architecture [11]. Short-term memory refers to information that is currently being held in the mind and long-term memory refers to information that is stored [11]. Both short and long-term memories cater for different modalities such as verbal and spatial information. Figure 1 illustrates an overview of memory systems which Ward[11] adapted from Gazzaniga et al. [12].

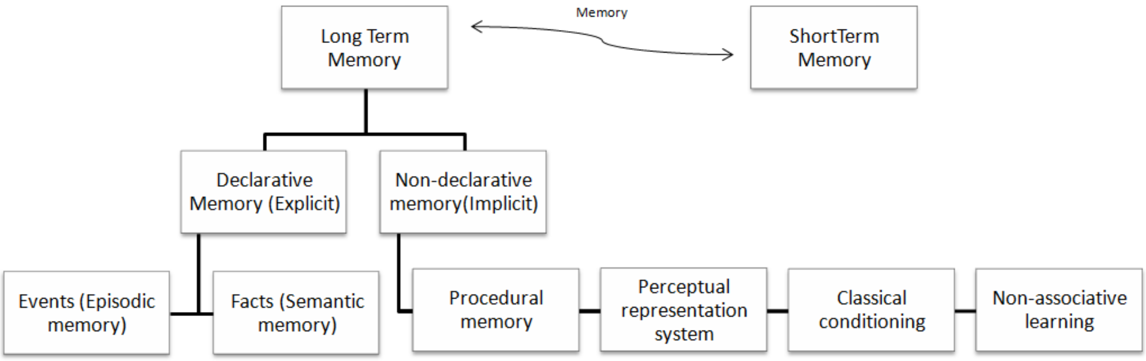

Figure 1: Overview of Memory Systems Adapted from Ward[11]

Working memory comprises a set of central processes that allows conscious thought to occur and has been shown to play a central role in activities such as reasoning and reading comprehension [13]. Within the cognitive focused literature the most useful framework for describing working memory is that developed by Baddeley and Hitch[14]. This framework was subsequently revised by Baddeley[15] and is shown in figure 2.

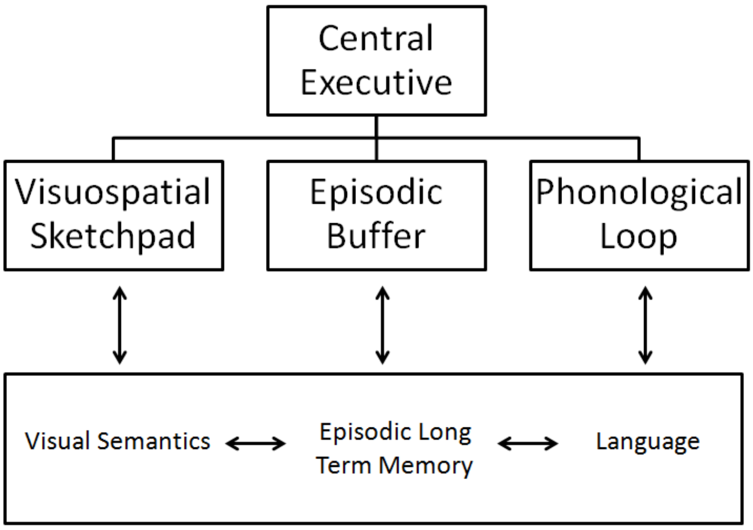

Figure 2: Components of Working Memory System [15]

Although working memory holds and manipulates information from different modalities there are separable areas, which deal with different forms of data. Visuospatial working memory is a separable component which has been shown to be separate from the verbal functions of working memory [9]. The visuospatial sketchpad is the component of working memory, which deals with information from the visual modality [14].

Processing Visual Information within Visuospatial Working Memory

Processing within working memory takes place under the control of the central executive which allocates the attention and cognitive resources appropriate to the task or situation [16].

The central executive plays a crucial role in reasoning tasks as it allows the subject to focus attentional resources on the more critical information to the task while disregarding less important information [8]. Visual information therefore is generated and processed within the visuospatial sketchpad of working memory under the control of the central executive.

There are a number of different theories regarding the generation, maintenance and processing of visual-mental imagery in working memory. Perhaps one of the more influential models is that of Kosslyn[17] where it is hypothesised that mental imagery occurs in a short-term visual buffer of activated representations in long term memory. This process can also be further fractionated into image generation, maintenance, manipulation etc. [8]. In order for this theory to become more plausible, visuospatial working memory needs to be thought more of a workspace than a gateway between perception and long-term memory. Logie and Sala[9] discuss the idea that sensory information (the item being perceived) can activate stored representations in long-term memory. Working memory is then multi-modal and can integrate data from both sensory input and stored long-term representations. Figure 3 illustrates this concept.

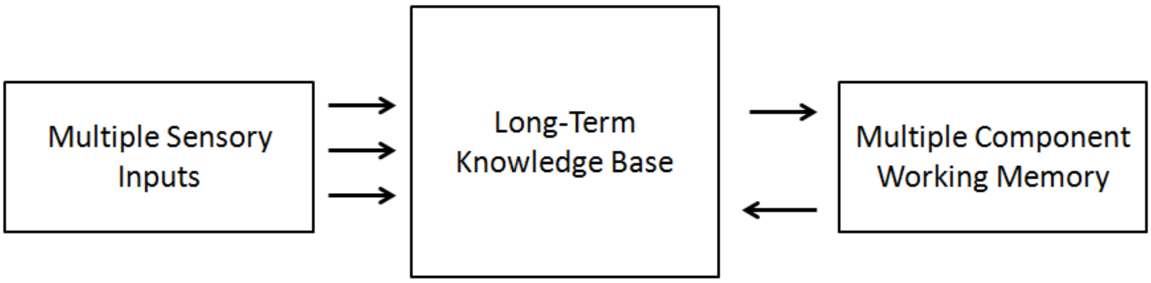

Figure 3: 'Workspace' Model of Working Memory [9]

As the literature presents, the process of generating and maintaining visual-mental imagery is a complex and multi-faceted procedure within working memory. It is a process which is also susceptible to deficiencies such as *unilateral spatial neglect* which involves an inability to cognitively process elements of a mental image [9]. This is a deficiency that is normally caused by physical damage to areas of the brain. Other deficiencies, which can occur in healthy brains, can be caused by issues such as *extraneous cognitive load* which interferes with processing performance and maintenance of attentional resources [18]. A potential issue of conditioned representation cited by Lane et al. [4] is specific to the process of generating and manipulating visual-mental imagery and hence warrants further investigation within this study.

Method

The research method presented in this paper is centred around the *Enlightenment* activity devised by Lane et al. [4] which involved the generation, maintenance and communication of visual-mental images. This activity was originally devised as an intermediate task, which facilitated students' progression from perception-based sketching activities to more conceptual tasks. The study was conducted within a core graphics module for Initial Technology Teacher Education (ITTE) students at the University of Limerick. This study is exploratory in nature and focuses on the possibility of conditioned representation, an issue eluded to by Lane et al. [4], occurring within students' approaches to generating, maintaining and communicating visual-mental imagery. It is hypothesised that by retrospectively analysing students' graphical representations of mental images, any anomalies in the cognitive process of generating, maintaining and communicating the images would become apparent.

Approach

The students were tasked with generating visual-mental images of five separate geometric configurations as used by Lane et al. [4]. These are illustrated in figure 4 and range from a relatively simple to a more complex configuration. Complexity of geometric configurations is generally defined within the literature as relating to the number of features (such as vertices) which the object contains [19]. The more features present within an image/configuration, the more complex it becomes. The validity of these tasks has already been established in a previous research study by Lane et al. [4] and they were utilised within this graphics module to develop sketching expertise and visualisation abilities.

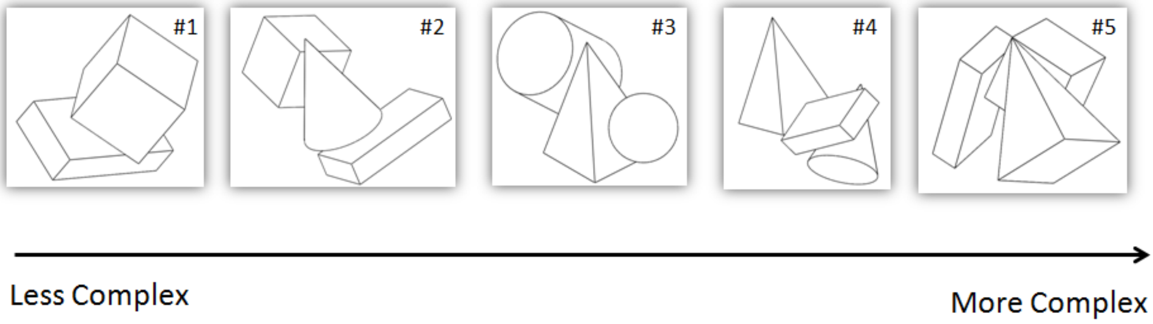

Figure 4: Enlightenment Activities Used for the Study [4]

Participants

The participants in this study were 3rd year ITTE students participating in a core graphics module at the University of Limerick. They were chosen as part of their core study focused on the development of sketching expertise and visuospatial reasoning, which made them ideal candidates for this research. The activity, which was the primary focus of the research study, was also a compulsory element of this graphics module and hence the students' degree course. These students have also participated in three previous graphics modules at the university and have developed the requisite visualisation skills and geometric knowledge to allow them to complete this task effectively. There were a total of 118 students.

Implementation

The task was completed within the tutorials for this particular graphics module as part of the core activities aimed at developing students' visualisation and sketching abilities. The geometric configurations were presented on a PowerPoint presentation with a blank slide following each object. The students were given one minute to inspect the geometry where they were not allowed to sketch anything. After this minute was up, the PowerPoint was advanced to a blank screen, after which students were asked to graphically communicate the visuospatial image they had generated and maintained in working memory.

Findings

The purpose of this research study is to investigate possible anomalies within visuospatial working memory through retrospective analysis of students' graphical sketches. Particularly, the current study is looking for evidence of standardised representations of the geometric configurations, which were originally presented to students in an unconventional format (figure 4).

Figures 5 - 8 contain evidence of this issue taken from a sample of student portfolios (*n=118*) and range from large deviation (figure 5) to a smaller deviation (figure 8) in communicated orientation. In order to illustrate the degree of variance from the geometric configurations that students were asked to visualise and communicate, a superimposed wireframe model of the original objects has been placed on top of student solutions in the second part (b) of the image. The first, second and fifth configurations were chosen to investigate the issue of standardised representation as they vary across the continuum from less complex to more complex.

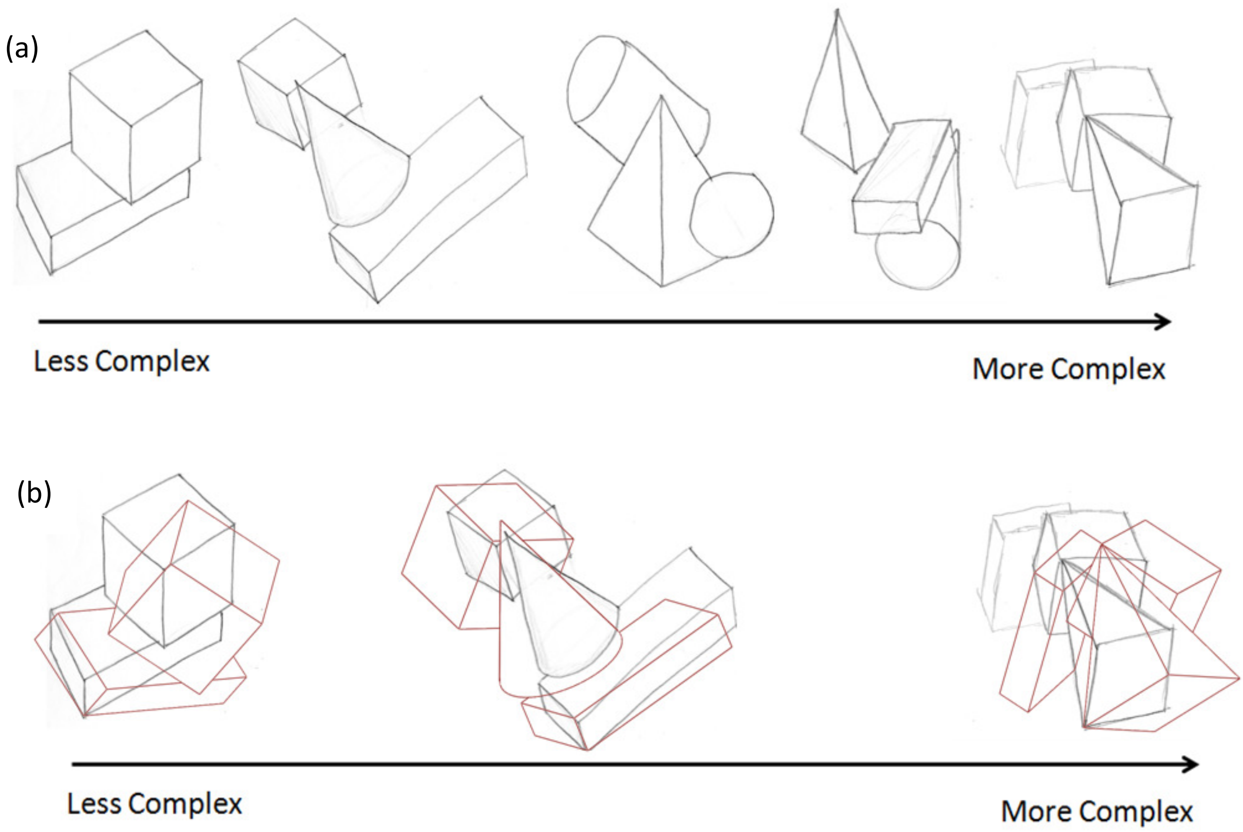

Figure 5: Solutions Presented by Student 1 (a) and Superimposed Images Showing Degree of Variance (b)

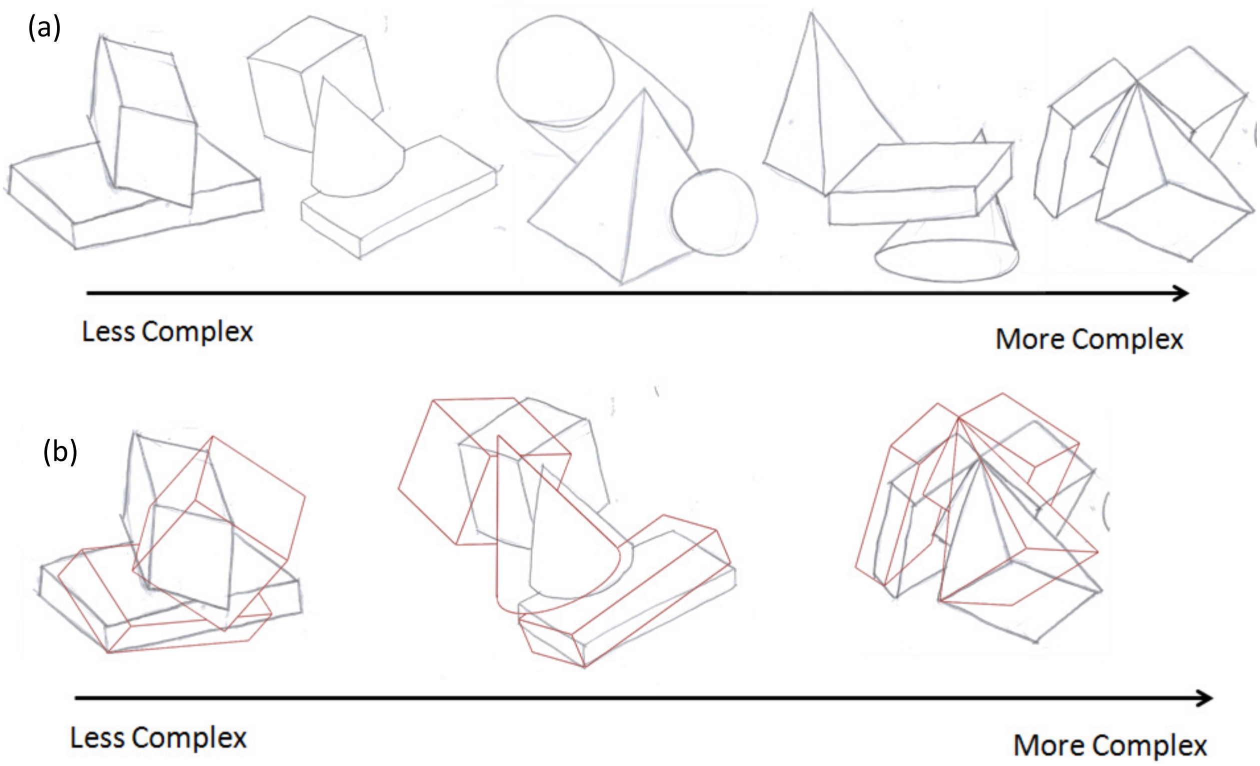

Figure 6: Solutions Presented by Student 9 (a) and Superimposed Images Showing Degree of Variance (b)

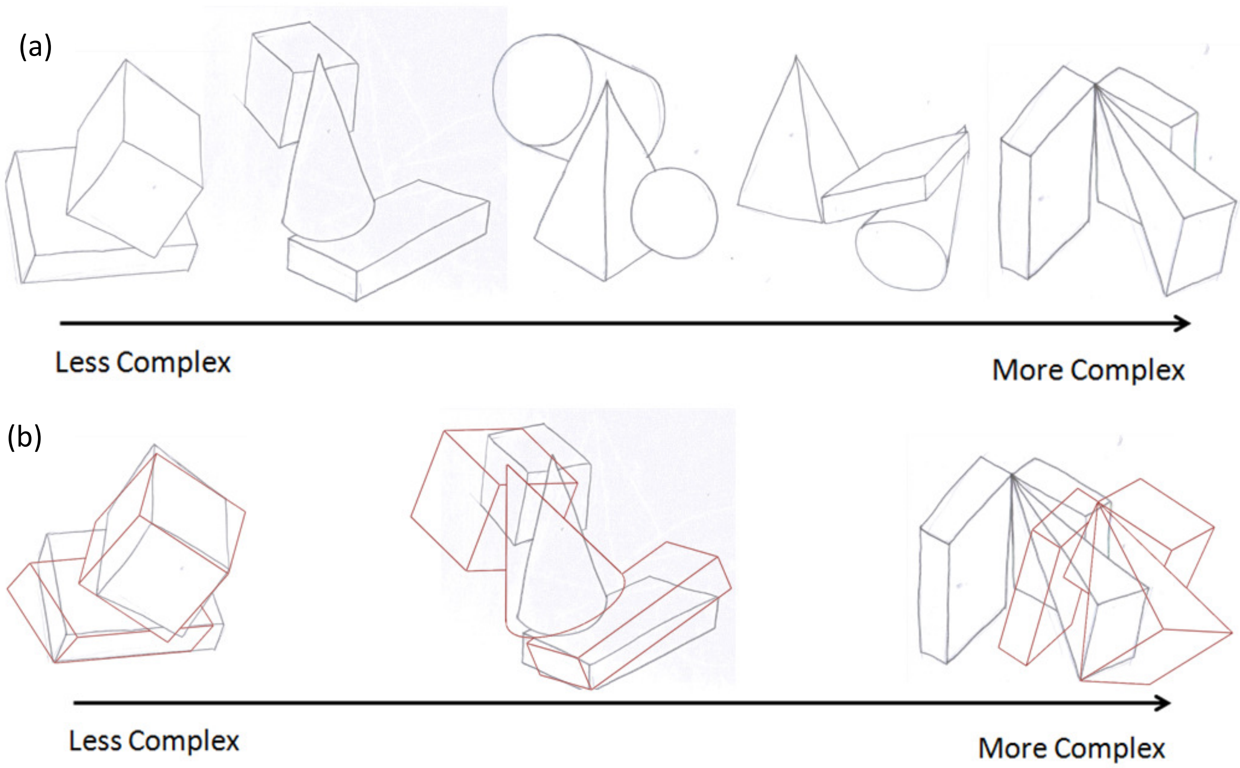

Figure 7: Solutions Presented by Student 6 (a) and Superimposed Images Showing Degree of Variance (b)

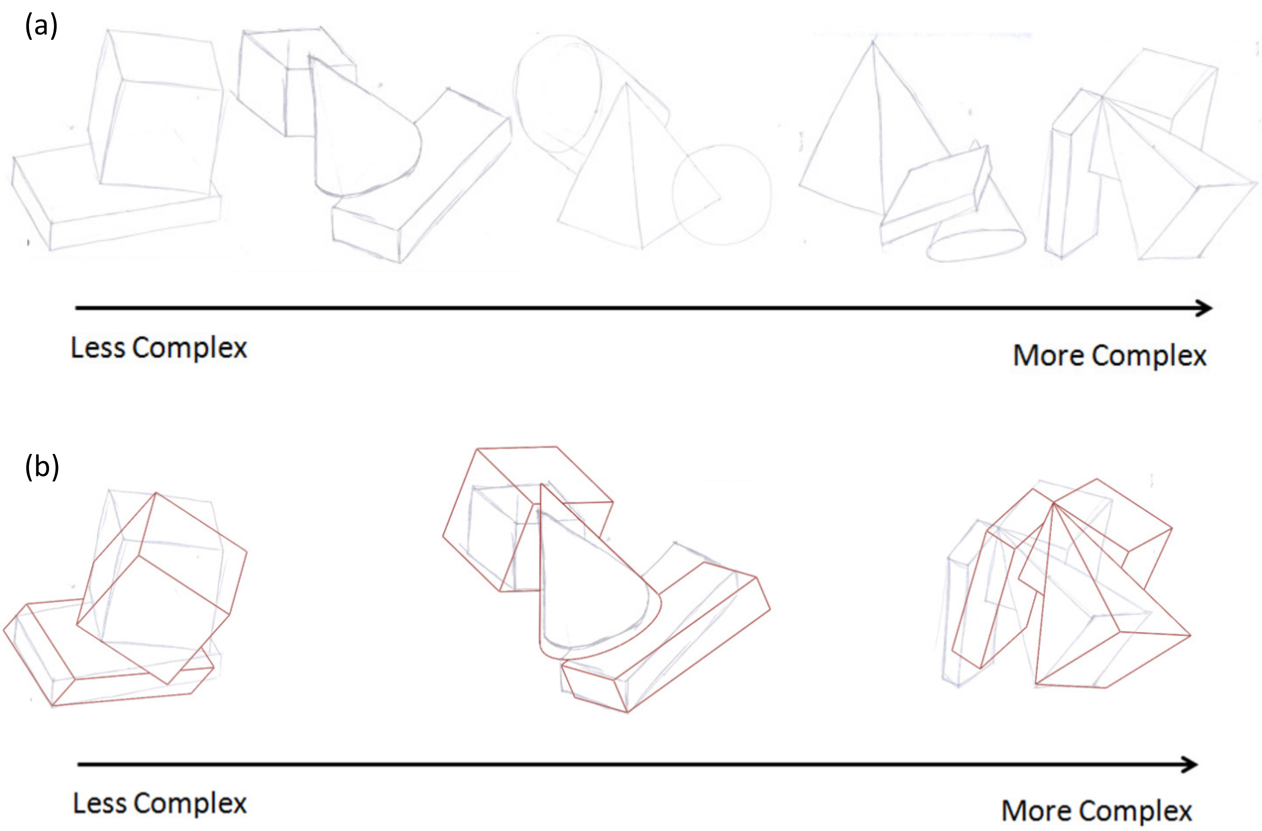

Figure 8: Solutions Presented by Student 11 (a) and Superimposed Images Showing Degree of Variance (b)

As can be seen in figures 5 - 8, students generally communicated a good representation of the geometric configuration originally presented to them. However, on inspection of part (b) of the images it can be seen that there is some variance regarding the orientations of the objects. Taking the first object in part (b) of images 5-8 it is evident that the base of the configuration (rectangular solid) has been communicated in a more standardised orientation than what was presented originally. The edges of the base component have been re-orientated to a more vertical position. Figure 8 (b) illustrates this quite clearly for student 11 where it is apparent that the rectangular solid element has been represented in a standardised orientation which is almost dimetric. The second part of the first configuration (the cube) has also been graphically represented with the edges in a more vertical orientation once more. A clear piece of evidence for this issue comes from student 1 (figure 5 (b)) where it can be seen that cube has been represented in a near isometric orientation.

This trend is also evident in the second configuration, which contains three geometric solid elements. Again it can be seen in figure 7 (b) that student 9 has represented the base element (rectangular solid) with the edges more vertical in orientation than that which was originally presented to the students. Another interesting trend among the solutions for configuration two is the orientation of the cube element, which varies quite significantly from the presented orientation (see figures 5-8 (b)). Taking figure 5 (b) for student 1, it can also be seen that the three solid geometries have been communicated with a similar axial direction. This is especially clear for the cube and the rectangular solid. This trend is noticeable in the majority of the solutions where the edges of the cube and rectangular solid seem to be somewhat collinear.

In general, the fifth configuration was communicated the best in terms of orientation compared to the first two configurations. The fifth configuration was the most complex geometric configuration (see figure 4). Although there is some variance between the communicated solutions and those that were originally presented, the orientations, which were communicated, were more accurate than the first two geometries. Figures 6-8 (b) highlight this trend well while student 1 (figure 5 (b)) had difficulty communicating the correct orientations of the solids.

Discussion

The qualitative data obtained during this research study provided a rich source for exploring possible issues regarding visuospatial working memory. In general, the students communicated the geometry well by means of graphical sketches. However, communicating the orientation of the geometries accurately was an issue, which is illustrated in figures 5-8. As presented in the results, there was evidence of a trend towards representing the geometries in a more standardised orientation than that which was originally presented. The area of visuospatial working memory is a complex domain which has only begun to be researched in depth recently [9]. There are a number of possible explanations, which may account for some of these 'standardised' solutions.

One possibility is that there is an issue occurring during the encoding stage of the task. In other words, when the image is presented to students it is perceived and then processed in a standardised orientation. This seems a plausible argument if we are to consider visuospatial working memory as a workspace where active generation can occur (see figure 3). This also means that the onset of the stimulus has direct access to long term visual memory as well [9]. The objects that were chosen for this task are directly related to the students' course of study. The majority of text books and learning resources available for graphical education in Ireland tend to utilise predominantly standardised illustrations (isometric etc.) and this is what students are most experienced with given that they have studied three previous graphical education modules. The generation of an image in the visuospatial sketchpad of working memory involves processes from both the act of perceiving a stimulus and utilising information related to the stimulus which is activated in long-term memory [7, 17].

As Frost[20] discusses, much of our visual memory is very difficult to separate entirely from the verbal system and one can often take precedence over the other depending on the situation. It is plausible that the students' long-term store of information regarding the solids presented in this task has been coded in a standard orientation and possibly using a coding system which has become more verbal and semantic than visual. The geometries may have been coded verbally by using a verbal descriptive system, which is amodal in nature. Semantic coding may also have been utilised where the representation of the geometry in long-term memory has been assigned to some class, possibly one governed by a pictorial projection system. This could be due to the conditioning effect, previously discussed by Delahunty et al. [2], where the overly technical approach to graphical education has placed limitations on students' ability to develop more robust visuospatial cognitive competencies. The results here may be an interference with the act of generating the visual-mental image in working memory by the intrusion of stored conditioned representations in long-term memory.

This concept is also similar to Van-Sommers[21] theory of *semantic preoccupation* where the repetition of constructing a representation in a standardised manner restricts the individual to utilising merely formal construction principles. Van-Sommers[22] has demonstrated that individuals generally follow a set of underlying cognitive principles in the production of graphic representations such as starting in a particular location or using accretion (adding further geometric representations to a base geometry to create a whole).

An interesting finding that occurred during this study was the difference in performance on the less complex geometric configurations (1 and 2) and the most complex geometric configuration (5). In the majority of cases students performed better in their representation of the fifth configuration with regards orientation. A possible reason for this may be the relationship of the complexity of the configuration and the maintenance process in visuospatial working memory. The less complex configurations (1 and 2) may have been more passively maintained in visuospatial working memory and therefore more susceptible to interference from long-term stores. The more complex configuration (5) by propensity would require more attentional resources from the central executive in order to maintain it in working memory and is therefore more active in terms of using long-term stored information. Bruyer and Scailquin[8] have discussed the possibility that 'simple' maintenance is passive and can occur separate of the central executive component of working memory. It is also possible that by the time students' engaged with the fifth configuration they had sufficient experience to complete it more efficiently however students did not receive any formative feedback while completing the tasks.

These possible limitations within visuospatial working memory have implications for a wider graphical education context particularly with relation to conceptual design and applied problem solving. The generation, manipulation and synthesis of visual mental imagery has been shown to be a critical set of skills in this area [3, 5]. It is also critically important that students are able to synthesise a variety of graphical information to solve applied problems [4]. If students' cognitive representations of these geometries have become overly standardised as a result of previous learning or possibly inflexible due to inappropriate coding processes this may place severe limitations on students' visuospatial working memory capacities and have serious implications for graphical problem solving and creative discovery.

Conclusions and Future Work

The intention was to further explore the possible existence of deficiencies in generating, maintaining and communicating visual-mental imagery. There is evidence to support the hypothesis that there is some sort of anomaly occurring within visuospatial working memory. It could be due to an encoding issue where there is a significant amount of interference from long-term memory where the representations have been shaped by previous experience in the subject. Another possible area where the issue may reside is within the decoding process where students are tasked with the graphic representation of the geometries. Due to a possible over technical emphasis within graphical education, it is possible that the cognitive limitations on the production process have become more and more restrictive in nature. Students therefore, rely on formal passive principles in graphical construction. The influence of past experience and memories has a significant effect on what we perceive [23]. This possible issue could have a significant impact on the nature of contemporary graphical education.

The study provided rich qualitative data to indicate that there is a possibility of underlying issues within visuospatial working memory. The exact nature of the issue that may be contributing to this restriction in the generation and maintenance of visual-mental images in visuospatial working memory is unclear from this study. The data was limited to the production of student solutions and will likely require a more in-depth approach in future work. A possible avenue to consider is the application of neuropsychological tools to investigate the cognitive processing underlying this activity. This concept was discussed by Delahunty et al.[24] and offers the possibility of a more objective and extensive investigation into the nature of cognitive activity which is occurring. This may allow the researcher to answer questions such as:

- What is the nature of the cognitive activity that is occurring during the encoding and the graphical production stages of the task?
- To what extent, if any, is the verbal component of working memory effecting the generation and maintenance of visual-mental images?
- What is the difference between the cognitive activity involved in processing the less complex geometric configurations and the more complex geometric configurations?

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