Engineering Design Graphics Journal (EDGJ)
Winter 2013, Vol. 77, No. 1
http://www.edgj.org

ISSN: 1949-9167

AC 2012-4274: INVESTIGATING STUDENT TEACHERS' APPROACH TO SOLVING APPLIED ANALYTICAL GRAPHICAL PROBLEMS

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ISSN: 1949-9167

Investigating student teachers' approach to solving applied analytical graphical problems

Abstract

Educating for a broad global context and developing problem-solving capacities are fundamental for living in an ever-changing global society. The ability to construct meaning and apply knowledge in a broad context is crucial within education [1] and it is the teacher's responsibility to facilitate this within the subject. This focus is difficult to embrace within the traditional formal schooling structures. Students can often achieve quite well by traditional assessment measures but often have difficulty when required to use this learned knowledge in new styles of problems [2]. Often students pass through the entire schooling system, and perform quite well, but are unable to utilise this learned knowledge in broader contexts [3]. It is future graphics educators that must establish the cultural norm. To do this an ability to apply and transfer knowledge from one context to another is crucial.

With the objective of analysing the complexities of applying previous graphical knowledge to a new context, groups of student teachers were given an applied analytical task based on the geometry of the regular polyhedra to solve. Prior to the prescribed task, students were given the opportunity to develop their graphical analytical knowledge and spatial skills through the completion of a coursework portfolio based on the content of the puzzle. A visual-verbal protocol analysis, similar to Montagueet al. [4] was employed to evaluate students' approaches to solving the puzzle and their ability to transfer previously learned knowledge and skills to a new situation as well as their ability to work collectively and communicate their ideas.

The findings indicate a significant inability to transfer knowledge and skills developed in the coursework portfolio to the new applied analytical task. Despite students' high level of performance in both the portfolio, which assessed graphical knowledge, and the Purdue Spatial Visualisation Test (PSVT), which examines ability to mentally rotate three-dimensional objects, many students were unable to employ an efficient approach to solving the applied analytical task. The paper discusses some key variables relating to performance in the applied analytical task and forms the basis for further research in the area.

Keywords: Problem-Solving, Technology Education, Performance and Transfer

Introduction

The need for creative problem solvers is a contemporary necessity for society especially given the ever-changing demands of modern living. Graphical education is one of the core subject areas that aim to develop these creative aptitudes. The research in this paper aims to examine the complexity of applying graphical knowledge to an abstract problem, which is a core skill in the context of technology teacher education. The primary focus will be on exposing the application of graphical knowledge and its relation to spatial cognition and analytical reasoning.

Investigating Problem Solving Capability

Within the graphics modules, which are core to Initial Technology Teacher Education (ITTE) at the University of Limerick, the primary aim is to develop graphically capable future

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educators. Capability is defined by Kimbell and Stables [5] as 'the power to produce and effect - a change and hopefully an improvement' (p. 18). Capability then involves the ability to implement such knowledge to the solving of a problem. Kimbell and Stables [5] distinguish capability from knowledge, competency and skills. They state that a person can be knowledgeable or skilful in an area but these on their own are not sufficient and should be thought of as contributors to capability. 'Capability involves additionally the ability to make good choices about what to do' (p. 18).

Within the graphics education modules at the University of Limerick there, is a core focus on problem solving and developing deductive reasoning skills. A robust foundation of domain specific knowledge is required to become an effective problem solver [6]. Often this distinguishing factor separates novice from expert problem solvers. In addition, Mayer (cited in Montague et al [4]) highlights metacognitive strategies as another key to successful problem solving. Metacognition or the ability to reflect on the way and how one thinks requires strategic and situational/contextual knowledge [7]. Students need to possess knowledge of strategies to employ but also understand when and where to employ these strategies relevant to the problem in hand. Metacognitive skills directly contribute to effective knowledge transfer [8] as it allows one to regulate the use of previously learned knowledge and skills depending on the context [9]. This is vital when one is faced with a new problem. Transfer of knowledge relates to the ability to apply knowledge, previously learned, to new contexts or situations and, as Broudy [3] discusses, should be at the heart of all educational organisations. In order for effective transfer to occur value must be placed on understanding subject matter rather than simply duplicating a set of processes (Judd 1908 - cited in Bransford & Schwartz [8]). The understanding and application of underlying principles forms one of the key focuses of graphical education.

Graphical education aims to develop students' creative problem solving capacities and reasoning skills through the study of plane and descriptive geometry but the assessment employed to evaluate these capacities is summative in nature as in most traditional educational structures. Research by Thorndike and Woodworth [2] has shown that even though students perform quite well on tasks that evaluate subject knowledge they will not necessarily transfer this learning to a new style of problem.

Future Graphics Educators

The research outlined in this paper is concerned with examining student teachers' ability to apply previously learned graphical analytical knowledge to an applied analytical task. Knowledge of geometry, the development of spatial abilities and problem solving skills are core elements of graphical education and hence of the third year ITTE graphics module at the University of Limerick. The ability to apply and transfer knowledge from one context to another is fundamentally crucial for future educators. As Petty [1] discusses it is important that students are facilitated in constructing their own meaning and this requires the teacher to be adaptable to pupils' needs and provide rich educational activities. The students in this ITTE module are the future educators and hence must be the ones who establish the cultural norm [10]. As Johnston-Wilder and Mason [11] discuss, much of the current educational practices take the form of 'knowledge transmission' between teacher and student and has the negative effect of constraining knowledge to one domain or context. The aim of this module was focused at challenging these traditional beliefs.

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The module had a significant focus on freehand sketching of geometrical concepts, which has been shown to improve spatial abilities [12] as well as allowing students to explore with freedom to 'negotiate meaning' [11]. Sketching, a form of cognitive modelling, allows students to refine their cognitive processes [13] and make sense of new concepts.

Mechanical drawing also formed a significant element of the module and is a valuable tool in developing thinking in three dimensions [14]. The development of sketching and drafting competencies aids in the representation of abstract concepts [15]. These mediums of learning were complimented by pedagogical activities such as discussion and group work, which is active in nature and involves students constructing meaning [1] and fostering understanding. The module aimed to move away from traditional pedagogical practices such as knowledge transmission, which can be stifling for a contemporary curriculum [10].

The pedagogical strategies were implemented to aid students in constructing their own meaning in relation to the subject matter and coursework portfolios were utilised to allow students to evidence their learning of graphical analytical knowledge.

Method

The study employs an action research approach to investigate students' ability to solve an applied analytical graphical problem following the knowledge acquisition stages of a graphics module. The problem was focused on the solving of a geometric puzzle, which was directly related to the duality of the regular polyhedra. Three of the regular polyhedra the Cube, Tetrahedron and Octahedron, were the focus of a core topic within a Design and Communication Graphics module at the University of Limerick.

The regular polyhedra form a significant element of projection systems and therefore a clear knowledge of the topic is essential for future technology teachers. The regular polyhedra are a logical progression from students' previous knowledge of plane geometry such as regular polygons, the key progression being a move to three-dimensional geometry. Studying the geometry of the regular polyhedra provides a clear insight into students' ability to manipulate regular geometry.

The teaching of the subject content was not merely focused on the mechanical drawing of prescribed problems but on the deeper exploration of geometric relations and principles. A coursework portfolio was used to develop students' graphical analytical knowledge where students were encouraged to include sketches and parametric models of core principles as well as mechanically drawn solutions in their final submission. Marks were then awarded for evidence of exploration of principles and their respective application to problem solving. A sample of work taken from several portfolios is shown in figure 1.

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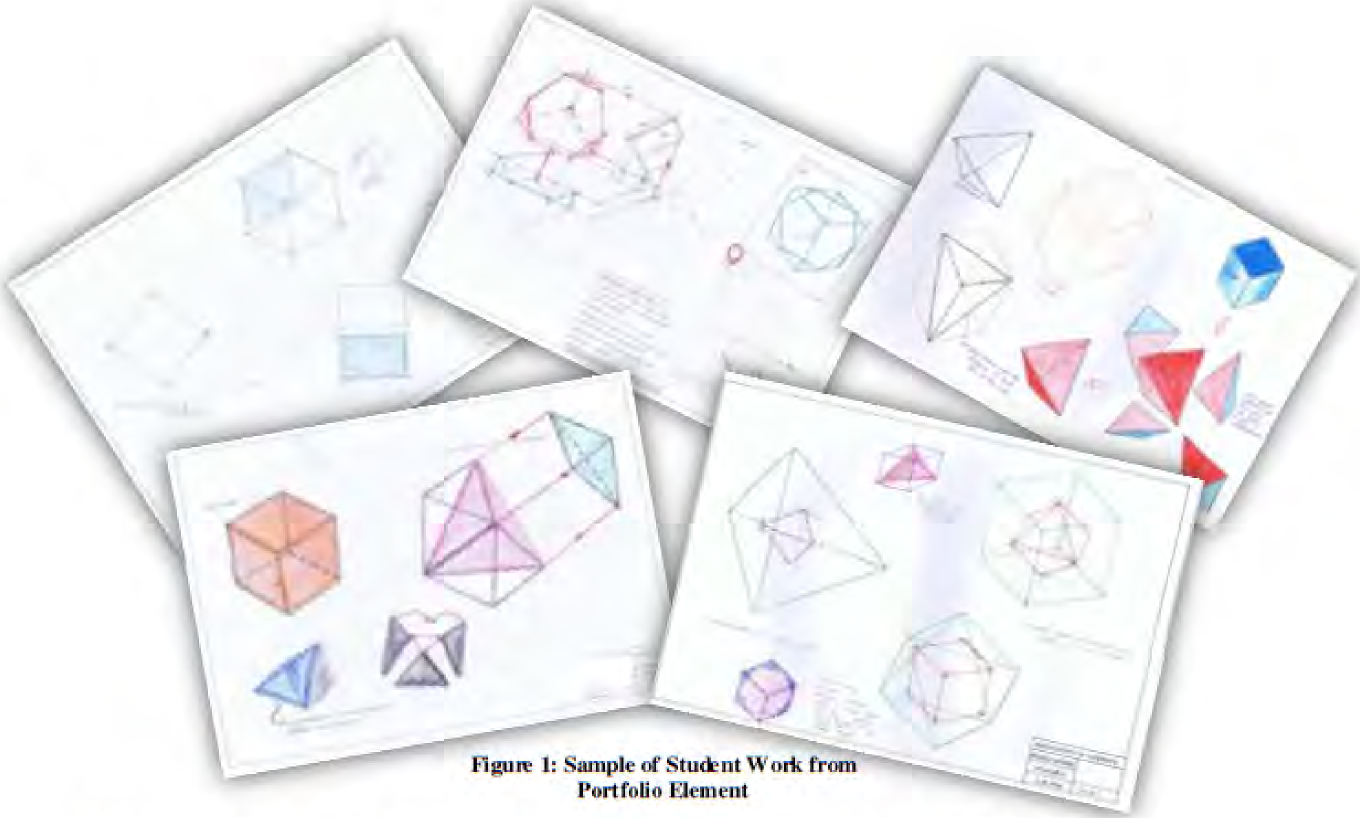


Figure 1: Sample of Student Work from Portfolio Element

The graphical analytical knowledge developed during the module was one of the key indicators relating to performance in the puzzle task. It was hypothesised that in order to solve the puzzle efficiently, the participants would have to apply their graphical knowledge and in particular knowledge of regular geometry. Another area that was postulated to be fundamental to the task was spatial ability and in particular spatial rotations as the puzzle was focused on the manipulation of three-dimensional geometry.

A significant focus of the graphics module was the development of spatial skills and problem solving aptitudes. Students were presented with several problems, during their lab sessions that were abstract in nature and required a significant element of exploration and visualisation. A sample of these problems, taken from Graphics in Design and Communication [16] can be seen in figure 2. These problems coupled with teaching strategies such as group collaboration, peer teaching and peer assessment aimed to develop deductive reasoning capacity and communication skills. In order to assess the standard of spatial reasoning skills relating to mental rotations among the ITTE students, the Purdue Spatial Visualisation Test (PSVT) was employed as the second ability indicator within the module. The reason for its use was to provide a comparison of spatial ability within the groups and to provide a basis for exploring whether the students relied on their spatial skills during the task.

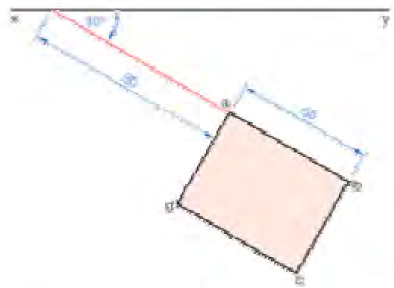
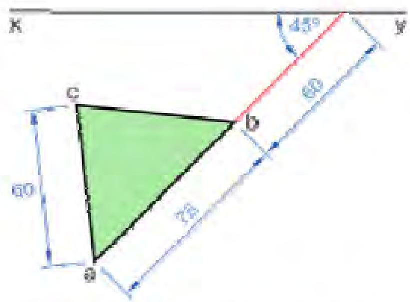
Problem Statement	Problem Image
The plan of a square abcd is inclined at 40 degrees to the HP. The edge ab rests on the horizontal plane. The square is the base of a cube. Draw the plan and elevation of the solid.	
The plan of the base of a tetrahedron is shown. Edge ab rests on the horizontal plane. Draw the plan and elevation of the solid	

Figure 2: Geometrical Problems on Regular Polyhedra (Anderson 2007)

Approach

The research study employed a live recording approach to capture students' approach to solving an applied analytical task comprising of a geometric puzzle based on the duality of the cube, tetrahedron and octahedron. It was decided that the task would be administered during one of the tutorial sessions and that the recorded solutions would be analysed retrospectively in order to reduce any disruptions to the lessons. As well as a visual recording of actions, a verbal protocol analysis was also utilised in order to gain a deeper understanding of students' reasoning processes. The use of think-aloud verbal protocols provides the researcher with rich data relating to students' reasoning abilities during a task [4]. Students were instructed to verbalise as much of their thought processes as possible during the task to gain a deeper insight into their application of graphical knowledge.

To clarify the approach students employed during the problem two post-task questions were posed to each group:

- Can you describe the relationship between the solids involved in the puzzle?
- How would you classify your approach to the problem? I.e. did you use the geometry of the solids or did you focus on their relative size and volume?

Participants

The participants in this short case study were third year undergraduate ITTE students. Students were asked during their tutorial if they would like to participate in a short activity involving the solving of a geometric puzzle. The students were informed that the activity was directly related to the content of the lesson that was being taught and they did not have to take part if they did not wish to. The students were also assured that only their hands would be recorded in the video and it would be completely anonymous. Twelve students from each tutorial group volunteered for the activity (*n=36*). The participating tutorial groups were further subdivided into smaller groups of three for logistical reasons (the workspace was

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limited due to the tutorial running concurrently) and asked to complete the task at the top end of the room away from the rest of the class. This ensured that the other volunteer participants could not see the current group's strategy.

Design and Implementation

This study centred on the solving of a geometrical puzzle that was based on the regular polyhedra and a number of other irregular solids that are assembled to form a cube. Figure 3 illustrates a CAD model of the puzzle and the associated key assembly steps. The puzzle was constructed using card and can be seen in disassembled format in figure 4. The puzzle was presented in a disassembled version so that the students had no prior knowledge of the solution. They were informed that everything fits into the cube.

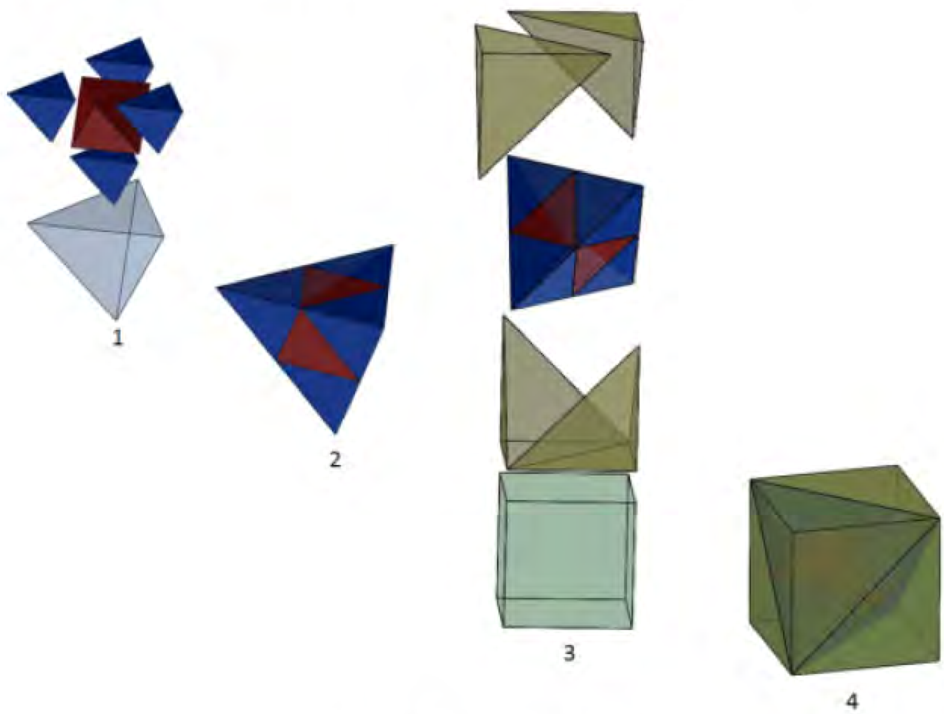

Figure 3: CAD Model of Puzzle

Figure 4: Disassembled Puzzle as Presented to the Students

The recording setup consisted of a laptop, which ran Debut Video Capture software, and a Logitech webcam, which focused on a circular area as, can be seen in figure 4. The circle

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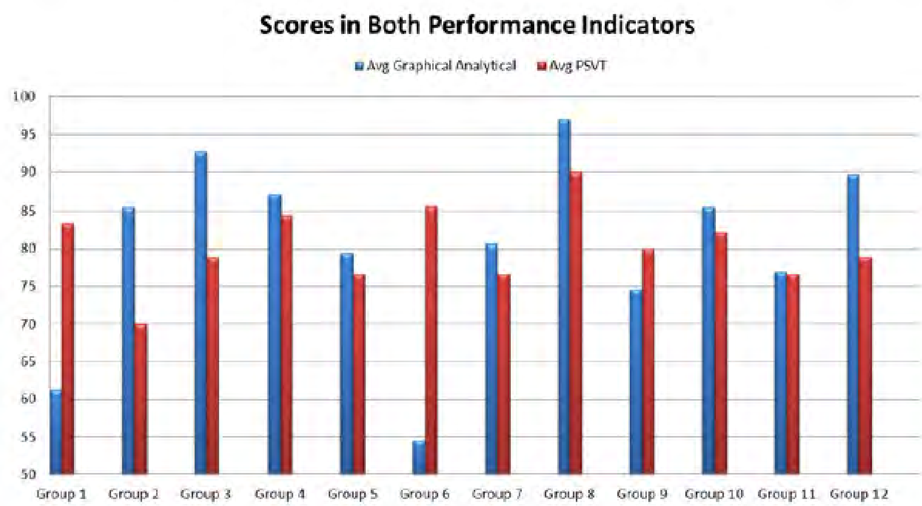
was roughly drawn on a sheet of A1 paper in order to ensure an optimum field of vision for the recording. The students were instructed to try to think aloud as much as possible during the task and when communicating with each other to speak as clearly as possible in order to obtain a clear recording for verbal analysis.

Results and Findings

The core aim of this research study was to ascertain students' ability to solve applied graphical problems following the knowledge acquisition stages of a graphics module. The performance of students, in both ability indicators (graphical analytical and spatial), is shown in figure 5 and will be discussed prior to the findings recorded during the applied analytical task.



Std Dev Graphical Analytical	5.25	8.33	11.06	8.33	11.83	38.31	8.97	3.78	14.88	4.81	8.39	16.29
Std Dev PSVT	15.28	20.00	22.68	18.36	20	13.88	5.77	5.77	8.82	19.53	14.53	12.62

Figure 5: Mean Scores by Group for Ability Indicators

PSVT Performance

Overall students performed well in the PSVT with an average score for the 36 participants of 24.1(80.2%) out of 30 and a standard deviation of 4.2 being recorded. This is however a high standard deviation given that students are trainee teachers of the subject and indicates a large variance in spatial skills among the students. Looking at the performance by groups in figure 5, it can be seen that there are strong mean PSVT scores in each of the twelve groups. The standard deviation (figure 5) within each of the groups is still quite high (none less than 5) indicating a significant amount of variance within the group dynamic.

Research by Sorby and Baartmans [17] highlight a number of factors which are significant in developing spatial abilities such as playing with construction toys like Lego as a child, gender and previous drafting experience. Given the diverse nature of students currently enrolled in the graphics modules at the University of Limerick and the fact that studying a graphical subject at second level is not a prerequisite for course entry, this variance in ability is understandable. All students within this module however have engaged with three technical graphics modules prior to this year and therefore should have developed spatial competencies as a result. Only two female students took part in this study so there is not sufficient data to

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analyse differences based on gender. It is possible that the prolonged experience some of the students may have had by studying a graphical subject at second level is a contributor to the variance in ability scores within this indicator.

To gain a clearer picture of the spatial ability of the student teachers, involved in this study, it is necessary to compare their results to the performance scores presented in previous research. Yue [18] analysed the spatial abilities across a number of educational levels including third level students of engineering and technology subjects at Essex Count College, NJ. It was found that first and second semester college freshman students recorded mean PSVT scores of 65% and 69%. College sophomores (2nd year students) were also analysed and recorded a mean score of 79%. It should be noted that all these mean scores were recorded in different subject modules relating to engineering and technology. Taking the scores recorded by Yue [18] into account it can be inferred that the ITTE students in this study in general possess relatively strong spatial abilities.

Performance in Graphical Analytical Element of the Module

The performance in the graphical analytical element of the module was also of a good standard with the average score obtained at 80.4% for the 36 participants. The standard deviation was recorded at 17.1 indicating a significant amount of variation among the students recorded. Mean performance scores and standard deviations for each of the twelve groups can be seen in figure. Again, there was significant variance recorded within each group reflecting the diverse levels of ability within the module. Students were graded not only on their ability to complete mechanically drawn solutions to problems but also on the level of exploration evident in their final submission. The results demonstrate a generally strong knowledge of plane and descriptive geometry among the students.

Comparisons of Performance Indicators

In terms of mean performance, nine of the twelve groups performed better in the graphical analytical element of the module than in the PSVT. Group 6 displayed the lowest mean score in the graphical analytical element (54.5%) and group 2 displayed the lowest mean score in the PSVT (70%). Group 8 scored highest in both performance indicators (97% and 90%) and had the lowest standard deviation (see figure 5). This indicates that students of group 8 had the most similar ability of all groups as measured by the graphical analytical element and the PSVT. Overall, eight groups had a higher standard deviation in the PSVT than in the graphical element. This indicates that the students' ability levels, within their respective group were more similar in the graphical analytical element than in terms of spatial ability. Group 6 had the largest standard deviation in the graphical analytical element at 38.3 indicating a significant amount of variance in ability level.

Performance in Puzzle Solving Task

Overall, the performance observed in the task, across eleven of the twelve groups, was quite poor. The dominant approach observed during the visual analysis seemed to lack the higher order metacognitive skills one would associate with effective transfer. Many of the same actions occurred in all twelve video solutions so in order to present a clear set of observations, groups 6, 8 and 12 were selected. Groups 6, 8 presented slightly different scores in the performance indicators and group 12 were most successful with the applied analytical task. A CAD model is included to clarify the students' actions.

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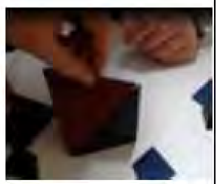
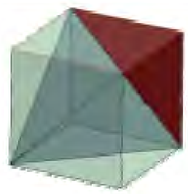
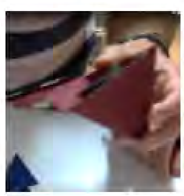
Verbal Protocol	Live Image	CAD	Analysis
Time: 00:13 **Student A:** "So I reckon the red one fits into the box but it must be tilted because it is higher than it and then something will have to go under it to make it tilt then"			Student A is clearly leading the approach here and there is a good deal of planning occurring. It would seem that their initial thoughts are on size and volume.
Time: 00:34 **Student B:** "Is this edge the same length as that diagonal so it would fit in"			One of the students has posed a question and now begins investigating himself. He recognised that the edge length of the tetrahedron is the same as the short diagonal. Students have not acknowledged it is a tetrahedron yet
Time: 01:15 **Student A:** "Perfect so if we take the red triangle out and then try to form a cube around we can see if they will all fit"			Students are exploring if they can form a cube with the irregular solids now. Student A is clearly dictating the approach. No input from student C so far. Students have created a cube with the solids - approach is based on filling space.
Time: 01:53 **Student B:** "This guy goes in here now, in the centre?" "Oh in the bottom first" **Student C:** "No it has four sides how can it fit?"			Students are having difficulty placing the octahedron in the tetrahedron. Student C is having difficulty visualising the orientation while student B is continuing with his own approach and is tentative with his comments every sentence ends with a tone indicating uncertainty.
Time: 02:14 **Student B:** "Oh I have it look!"			Student B persisted in rotating the object until it fitted. The other two students at this stage displayed very little activity. Student A was exploring the irregular tetrahedrons briefly.
Time: 02:25 **Student B:** "I think that seems to complete it does it?" **Student A:** "Yeah that's it good man!"			Again, there is no definitive statement from student B; all of his comments have been capped with a tentative remark despite being correct. Student A acts to reinforce him at this stage.
Time: 02:34 **Student B:** "Now what way did we say that was again?"			Despite having already placed the tetrahedron in the cube correctly, he attempts to fit it in incorrectly this time. Could this be a reinforcing behaviour? I.e. ensuring that this has to be wrong Student places the tetrahedron in himself after a number of rotations and they complete the puzzle at 02:43

Table 1: Group 6 Approach to Solving Puzzle

Engineering Design Graphics Journal (EDGJ)
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http://www.edgj.org

ISSN: 1949-9167

Group 6 displayed the lowest mean score (54.5%) and highest standard deviation (38.3) in the graphical analytical element of the module. The high standard deviation is indicative of three students with very different levels of graphical analytical knowledge. The approach observed during the task showed very little focus on geometric elements and the majority of actions were centred on spatial attributes of the solids. Student A began with very purposeful statements and a great deal of planning prior to any physical action as can be seen at the top of table 1. The standard deviation of the group in relation to the spatial element of the module was far smaller and as can be seen students had a 'like minded' approach relating to spatial relations. Looking briefly at the group dynamic, student C had very little input into the task and student B was very tentative with any statement he made generally ending with a question. Student A was clearly the most confident during the task but did not seem to have the strongest application of knowledge to the task. He was, however, very good at reassuring student B when he was tentatively proposing ideas.

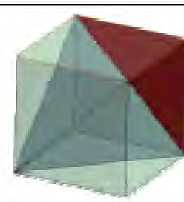
Verbal Protocol	Live Image	CAD Image	Analysis
Time: 00:08 **Student C:** "Right lets fit the four black ones into the red shape and the rest go around it"			Student C begins with a purposeful statement but exhibits poor visualisation skills. Assumes that all four irregular tetrahedron fit inside. Surprising when looking at PSVT performance
Time: 00:45 **Student B:** "This one fits in the centre, no it can't" **Student C:** "No it does yeah look"			Student B looks at fitting the octahedron into the tetrahedron but immediately dismisses his own idea. Student C then fits it in. Tentative approach exhibited by student B
Time: 00:58			There is no discussion at this stage, student C places the tetrahedron in the cube directly
Time: 01:14 **Student C:** "I bet you these go in the bottom of the box first" (Referring to irregular tetrahedrons)			Student C has first input at this stage and places irregular tetrahedrons in the correct position. Student have still not realised the position for the last mini-tetrahedron as can be seen in the live image
Time: 01:41 **Student B:** "Ah yeah I know we are missing one at the top of that look"			As student C is taking apart the tetrahedron element, student B states the space left From here student C places all the shapes in the correct position and the other two show no activity Tot time: 02:01

Table 2: Group 8 Approach to Solving Puzzle

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Group 8 recorded the highest scores in both the graphical analytical and spatial visualisation elements of the module as presented in the previous section. The first action observed (table 2) is quite surprising when this is taken into account. Student C attempts to fit the four irregular tetrahedrons into the red regular tetrahedron illustrating poor visualisation ability in the applied analytical task. In terms of the group dynamic, there was no clear leader here as was observed within group 6. Student B displayed a tentative approach where he immediately dismissed a correct idea of his own showing a lack of confidence in his graphical analytical knowledge. Student C reinforced his initial idea and thus the solution was progressed. Student B was also seen as the most active physically and in general, the amount of discussion was limited in comparison to group 6.

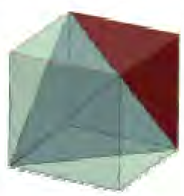
Verbal Protocol	Live Image	CAD Image	Analysis
Time: 00:23 **Student C:** "Now all the small ones go into the red tetrahedron around this black one (octahedron)"			Student fits the octahedron in correctly on the first attempt and then acknowledges in discussion, the space left for the small tetrahedrons. Student C is clearly leading the discussion here. There is a good deal of planning initially with little physical action. Students A and B are quiet at this stage.
Time: 00:42 **Student C:** "Ok so the tetrahedron goes in the cube" **Student B:** "But remember it has to be along the diagonals on it"			There is a significant amount of purposeful discussion in this approach and the students place the tetrahedron in correctly on the first attempt. Student A is slightly hesitant when placing the tetrahedron in until student B reminds him of the geometric relationship.
Time: 00:51 **Student A:** "Ok so the black ones (irregular tetrahedrons) must go in the left over space" **Student C:** "Yeah they go into the corners look"			Student A correctly identifies the position for the remaining irregular tetrahedrons and begins placing them in the cube. Student C reinforces the idea and the students quickly place the remainder of the puzzle together. Tot time: 00:52

Table 3: Group 12 Approach to Solving Puzzle

As can be seen in table 3, the approach of group 12 was much more purposeful and displayed a clear understanding of the duality of the regular polyhedra. The students' discussion with each other was directly centred on geometric relations and their corresponding physical actions were correct on the first attempt in the majority of instances. The group began by discussing a plan, which was directed, by student C and once this was decided upon, they progressed the solution physically. Student C displayed a robust knowledge of the relations learned in the graphical analytical element and a good ability to use them in the applied analytical task. The group dynamic in general was very direct and purposeful where students had a clear 'like minded' approach. Unlike the previous groups presented, all three students here were observed to contribute purposefully to the task for example where student B helps in refining his peer's idea when fitting the tetrahedron in the cube. Group 12 had similarly strong mean scores in both performance indicators (see figure 5) as well similar standard

ISSN: 1949-9167

deviations in both with 16.2 in the graphical analytical element and 12.8 in the spatial element. Although the standard deviations were high, they were high for both elements indicating a similar variance in ability for both indicators.

Student Responses

The results of the post-task questions are illustrated in figures 6 and 7. The post-task responses aim to clarify the approach that students adopted. The results demonstrate that the majority of groups had significant difficulty in recognising the relationship between the solids involved in the puzzle.

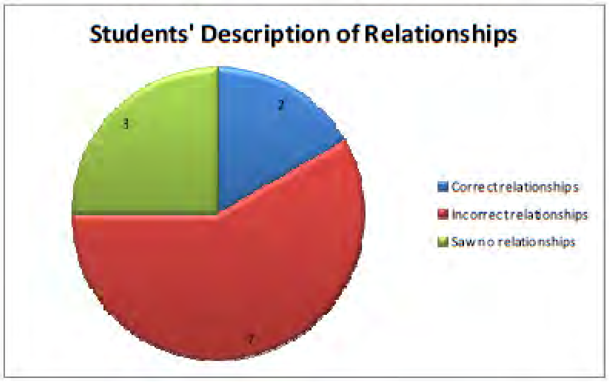


Figure 6: Results of Post-Task Interviews Relating to Description of Relationships

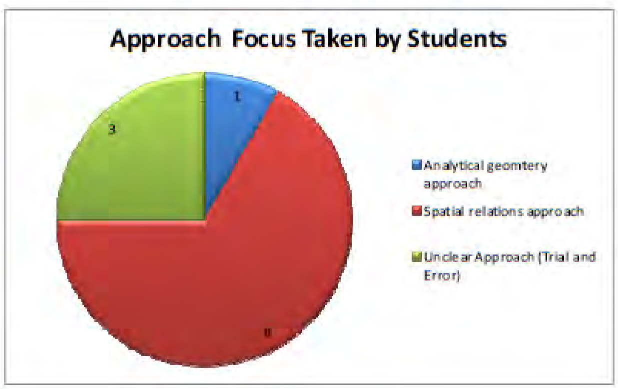


Figure 7: Results of Post-Task Interviews Relating to Approach Focus

During the post-task discussion, seven of the groups incorrectly described the relationships between the solids. Group 6 describe the relationship as follows *"they all had to meet in the corners of the cube"*. Three of the groups stated in their comments that they could see no relationship between the solids. Overall ten of the twelve groups were either incorrect or could not recognise the relationship between the polyhedra despite having explored their geometry extensively during the completion of the graphical analytical element of the module (See figure 1).

The approaches students adopted also varied although the dominant strategy acknowledged in the post-task comments was based on the spatial relations of the solids. Group 8 described their approach as follows *"Well we tried to imagine all the shapes as parts of the cube and then we moved them around until they fitted in the space"*. Three of the groups stated that they were uncertain during the solving of the applied analytical task and resorted to a trial and error approach. Group 2 commented, *"Well we knew that the shapes had to fit in the box so we kept rotating them until they fitted"*. Just one of the groups (Group 12) utilised an approach that was based on using analytics. They were able to describe the relationships between the three primary solids (Cube, Tetrahedron and Octahedron) and articulate a clear approach using the geometry of the solids to obtain the solution in the applied task. Group 12: *"Well we knew that the tetrahedron fitted in the cube along the diagonal of a face and that the octahedron must fit in the cube as well and then we just fitted the irregular ones around them"*.

The post-task comments helped clarify the approach that the students adopted in solving this puzzle and further highlighted an uncertainty in applying graphical analytical knowledge. As can be seen in figure 6, the majority of groups could not describe the relationships between the regular solids despite having scored generally high in the graphical analytical element of the module. Overall, an inability to effectively apply previously developed knowledge and skills and efficiently work as collective during the applied analytical task was established.

Discussion

The primary focus of this paper was to ascertain whether students could successfully transfer geometric knowledge acquired during a graphics module to the solving of an applied task. Students, in general, were unable to make the links between the regular polyhedra and establish a clear strategy. In a study such as this, which focused on the physical manipulation of geometry, the haptic tendencies of students may have been a significant factor. Previous research has shown physical interaction can enhance visualisation [19] but this element was beyond the scope of the current study.

Overall, the findings illustrate that eleven out of the twelve groups involved in the task did not successfully transfer this knowledge and relied either entirely on spatial relations or guesswork. Students in eleven of the twelve groups appeared to struggle with the puzzle despite having explored the geometric relations of the three regular polyhedra involved during the graphical analytical stages of the module (See figure 1).

Approach and Group Dynamic

The approach of group 6 (table 1) was a clear example of one which was based on spatial relations. The three students did not acknowledge any of the geometric solids by their correct name during the task and could not identify the relationship correctly in the post-task discussion. The reliance on spatial relations was not surprising given the poor mean score achieved in the graphical analytical element of the module and given the extremely high standard deviation of 38.3. Students in group 6 clearly had three very different ability levels in relation to graphical analytical knowledge and this was perhaps a reason they could not transfer the knowledge collectively to the applied analytical task. The group dynamic was diverse with student A leading most of the discussion and planning and student B displaying a lack of confidence in working with the group. Student C had very little input during the task, and when he did, displayed poor visualisation skills relating to fitting the octahedron into the regular tetrahedron (see table 1). The lack of confidence shown by student B is

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certainly noteworthy given that all students are future graphics teachers. Looking at the last section of table 1, student B can be seen to be placing the tetrahedron into the cube incorrectly despite having already achieved this action earlier. This activity is indicative of learning reinforcement where the student is reassuring himself, through reflection, that he has the correct solution by exploring incorrect options [20].

Group 8 achieved the highest mean scores in both indicators of the module (97% for the graphical analytical and 90% for the spatial elements) and the lowest overall standard deviations of any group. The students were very similar in terms of ability levels yet had difficulty in working collectively as well. Despite the strong mean score achieved in the graphical analytical element of the module, group 8 relied on the spatial relations of the solids for the majority of the applied analytical task. Student C displayed some very poor visualisation skills initially where he attempted to place the irregular tetrahedrons into the regular tetrahedron. There was a significant amount of diversity within the group dynamic. Generally, there was very little discussion recorded in this solution, most of the actions began with a student exploring their own ideas first, and then the other two would join in. Student B displayed a very tentative approach, immediately dismissing an idea of his own despite it being correct, it took reinforcement from another student to continue the solution.

Group 12 on the other hand displayed a significantly different approach, which resulted in a far more competent display of problem solving capability. As can be seen in table 3, their discussions with each other were purposeful and focused directly on the geometric relationships between the solids. The instances of mistakes, when placing the solids in one another, were far less as they considered the geometry before physically acting. The mean scores this group achieved in both performance indicators were quite strong (89.7% in the graphical analytical element and 78.9% in the spatial element) and the standard deviations were 16.2 and 12.6 respectively. There is significant variance in ability in both elements of the module; however, the dynamic of this group was far more direct and purposeful. The solution started with student C initiating a plan prior to any physical action. Once all were clear on the planned approach, they proceeded to piece the task together. Students were very active in refining each other's idea (see table 3 at 00:42) and confident in communicating with each other. The group were able to; correctly, express the relationships between the solids and their approach based on geometric relationships in the post-task discussion.

Uncovering Variables

The goal of the module was to develop graphically capable ITTE students. As Kimbell and Stables [5] discuss, a hallmark of capability is the ability to call upon previously learned task related knowledge as necessary when faced with a problem. The ability to transfer knowledge from a previously learned context to use in a new type of task is at the heart of effective problem solving and a fundamental expertise for future technology teachers. As can be seen only one group were able to utilise previously learned knowledge in solving this task as was identified in their post task comments where they clearly acknowledged the relationship between the regular polyhedra in their solution. Taking into account the success students had in the assessment elements of the module a significant issue becomes apparent. Despite students demonstrating a good standard of graphical analytical knowledge in the portfolio and a high standard of spatial abilities in the PSVT, there is an inability to employ the knowledge as a group in an applied graphical task.

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Thorndike and Woodworth [2] have shown that even though students may perform particularly well in assessment which measures subject specific content, they may not be able to transfer this learned knowledge to new types of problems or tasks. The group dynamic is also an important factor in performance within the applied analytical task. As seen in groups 6 and 8, communication was a problem for some students and these may have performed well in the spatial element of the module but have been unable to communicate their point effectively. This is a concern as the students are future teachers and communication of key principles is a crucial expertise.

The findings of this research study align with Thorndike and Woodworth's [2] initial findings on knowledge transfer and highlight a significant deficiency within students' graphical ability. However, the exact area where this deficiency lies is not yet clear. The root of the problem may lie within the assessment practices employed in the module. As noted earlier, the majority of students performed well in the graphical analytical element of the module, measured by the coursework portfolio, which aimed to assess their knowledge of plane and descriptive geometry. However, the students were unable to utilise this knowledge to solve the geometric puzzle presented and instead relied on other strategies. Seery et al. [10] discuss the value of the coursework portfolio and their findings conclude that it is possible to complete the course of study with presentation of 'neat *nonsense*' and a lack of understanding. It is possible that the deficiency lies in the ability to utilise the correct metacognitive skills within the problem-solving context. Metacognition is a necessary skill for effective knowledge transfer [8] and is used to evaluate cognitive processes during task performance [21]. An inability to utilise the correct strategic knowledge, which is a fundamental component of metacognition, is illustrated by the uncertain, trial and error approach observed during the task and identified in some of the post task discussions. The inability of students to implement the most appropriate heuristic for the problem is apparent in the findings.

Summary

When we take into account the high level of performance in the PSVT and graphical analytical elements of the module and compare them to the approach observed in the applied analytical task, it is clear that students were unable to employ the knowledge and skills effectively in solving the applied analytical problem. The issue appears to lie in the inability to transfer the knowledge and skills acquired during the module to further tasks. However, it is clear that the dynamic of the group has a significant influence on performance as well. Group 12 had by no means the strongest scores in the performance indicators and did not have a significantly lower standard deviation than any other group. The standard deviations in both elements were similar (see figure 5) indicating a similar variance in ability for both. However, group 8 also had a similar standard deviation in both elements and also the lowest overall which indicates a similar level of ability yet their performance in the applied analytical task was poor. The dynamic of group 12 is a distinguishing factor. Their communication skills were far better as was their confidence in discussing their ideas with each other whereas communication in group 8 was noted to be limited (see table 2). Group 12 displayed a stronger use of metacognitive regulation through initial strategy planning and refining each other's ideas as the task progressed, and this is perhaps the core reason for their success.

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Conclusion

The paper has presented a number of key findings relating to student teachers' ability to apply knowledge and skills form a graphical analytical context to an applied analytical task. It is clear that a high level of knowledge and skills, as identified in the performance indicators (figure 5), is not sufficient to ensure competency in applied analytical tasks. What is also apparent in this study is that the group dynamic has significant impact on performance and in particular the use of high order metacognitive skills to plan and refine an approach.

The research in this paper was concerned with exposing the complexity of applying previously learned graphical knowledge to a new style of problem. The findings demonstrate that students perform well in the knowledge acquisition stages of the module but collectively present significant difficulty in transferring this learned knowledge in a new applied analytical context. However, the exact deficiency in the application of knowledge is beyond the scope of this study. Could the issue primarily lie with the students' metacognitive skills and hence the ability to apply the correct situational heuristics? Could it be related to the poor communication skills and confidence levels noted in the observations or a willingness to work as a team? It is likely that both have a crucial part to play in this issue, which is quite significant in the context of teacher education.

The conclusion of this paper forms the basis of further research into the area of applied graphical problem solving, as it highlights a significant inability of these students to apply or transfer graphical knowledge to broader contexts as part of a group. Broudy [3] states that the ability to transfer knowledge in a broad context should be at the heart of modern education but concedes that this is not occurring within formal schooling. The majority of people find severe difficulty in applying what they learn in school to everyday life [22]. Performance in assessment elements does not necessarily prepare students for a diverse and ever-changing global society. As Eric Hofer discusses, it is the 'learner' that will be most prepared for the future whereas the 'learned' will have significant difficulty in coping with changing contexts.

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