# Balancing Curriculum Intent with Expected Student Responses to Designerly Tasks

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## Abstract

Design activities form an extensive part of design and technology education with a link being posited within the pertinent literature between the cognitive activity of learning and the cognitive activity of design. It is therefore critical that design educators' understand the effects that design constraints can have on the learning process. This paper aims to examine the potential to affect student responses and associated learning from design tasks based on the manipulation of task variables. A study was designed to examine the effects of two modelling systems – one parametric and one non-parametric – on the thought processes and design journeys of the students. The findings suggest that the use of parametric modelling can emphasis student thinking on technical considerations while the use of a freeform moulding CAD system affords a more creative orientation. Qualitative findings demonstrate the capacity of students to select appropriate strategies to complete the design task, further indicating that relaxing design constraints can support student learning in design activities. Considering curricular intentions to develop both technical and creative competencies, this study presents empirical findings illustrating how teachers can strategically design tasks which balance expected student responses with intended learning outcomes.

## Key words

graphical education, Design, Modelling, CAD, Learning, Curriculum intent

## Introduction

Graphical education was introduced into post-primary education in Ireland within the subject of Art and Drawing in 1923 whereby the graphical component was seen within the section named Mechanical Drawing and Design. The vocational origins of the subject are clearly illustrated through the inclusivity of technical draughtsmanship as an examinable skill, however design was also a core aspect of the subject as shown through its synthesis with art education (Seery, Lynch, & Dunbar, 2011). Examples of design activities within the subject included the design of posters, book covers, abstract compositions and fabrics (SEC, 1970).

Since its inception graphical education in Ireland has undergone a number of educational reforms (Seery et al., 2011) and has evolved into the contemporary subject of Design and Communication Graphics (DCG) at upper post-primary level. As one of the four subjects within the suite of technology education subjects in Ireland (Technology, Construction Studies, and Engineering form the remaining three) the overall agenda of DCG is to

contribute to the development of technological capability (DES, 2007a). In conjunction with this, DCG has a number of specific aims and objectives. While a wide variety of specific objectives exist such as developing visuospatial reasoning skills, developing graphical communication skills, and providing a basis for lifelong learning, two clear aims permeate the syllabus: developing creative and designerly competencies, and developing technical expertise (DES, 2007a). Specifically in relation to creativity, DCG aims to "prepare [students] to be creative participants in a technological world" by affording them the opportunity to "express their creativity in a practical and imaginative way, using a variety of forms: verbal, graphic, model, etc." (DES, 2007a, p.5) while simultaneously from a technical perspective students should be "familiar with the principles, concepts, terminology and methodologies associated with the graphics code" and be "able to produce neat and accurate drawings that comply with internationally recognised standards and conventions" (DES, 2007a, p.6). Clearly, the subjects' vocational and creative aims still exist and from a pedagogical perspective it is therefore critical that educators achieve an appropriate synthesis between them. One way this can be facilitated is by balancing expected student outputs with curricular intent through the strategic design of educational tasks which afford specific types of thinking and learning. To contextualise this approach within the subject's intended learning outcomes, its primary goal of developing technological capability must first be explored.

## Technological Capability

The concept of technological capability has traditionally been difficult to define (Gagel, 2004). A reason for this lies in the subjectivity in defining and measuring what makes a person technologically capable. Specifically within technology education in Ireland (DES, 2007a, 2007b), technological capability is defined as including:

- The understanding of appropriate concepts and processes
- Skills of design and realisation
- The ability to apply knowledge and skills by thinking and acting confidently, imaginatively, creatively and with sensitivity
- The ability to evaluate technological activities, artefacts and systems critically and constructively

This definition aligns almost perfectly with that of the Scottish Consultative Council On The Curriculum, who define technological capability as having an "understanding [of] appropriate concepts and processes; the ability to apply knowledge and skills by thinking and acting confidently, imaginatively, creatively and with sensitivity; [and] the ability to evaluate technological activities, artifacts and systems critically and constructively" (Scottish CCC 1996, p.7). Gibson's (2008) model provides structure to this definition by describing technological capability as the unison of skills, values and problem solving underpinned by appropriate conceptual knowledge. Black and Harrison's (1985) model adds an additional dimension to the term through their recognition of the dichotomy of designing and making. They define technological capability as being able "to perform, to originate, to get things done, to make and stand by decisions" (Black and Harrison 1985, p.6). Despite the variances in each definition, there are persisting commonalities. One trait which is regularly alluded to is the capacity to problem solve within the technological context. Within the confines of DCG and reflecting the aims of the subject, problem solving activity is encapsulated within

two interconnected forms; geometric problems and design orientated problems. The focus of this paper is to explore how, by controlling variables associated with design realisation in a design task, student output and associated learning outcomes can be manipulated to align more with creative competencies or technical skills.

## Designerly Thinking and the Cognitive Capacities Espoused within DCG

Design in education has been an area of substantial interest over the past number of decades. The 1970's saw an increased understanding of the design capacity of humans (Archer, Baynes, & Langdon, 1976; Cross, 1979) resulting in discussion about the necessity for the inclusivity of design in general education (Stables, 2008). Within DCG, design activity is conceptual in nature, however as the subject is within the suite of Technology subjects, recognition is given to the development of technological capability (DES, 2007a). Reflecting Black and Harrison's (1985) model, this recognition can be seen in that conceptual design is typically carried out with a view towards making.

Archer (1992, p.8) describes design as 'envisaging-what', differentiating it from technology which he offers the comparison for as being 'knowing-how' and further identifies design as embodying an "entirely different mental discipline". This mental discipline is broadly described as designerly thinking. Stables (2008, p.8) identifies humans as being "designerly by nature" in that being designerly is "a capability that exists as innate potential". Stables (2008, p.8) further discusses the derivation of the term 'designerly' from a culmination of human abilities, three of which being of particular importance in its conception; our ability to 'image' things in our mind, our ability to both cognitively and externally manipulate those images and our ability to utilise those images in the creation of future realities. Baynes (1992) posits that 'design intelligence' could be a unique form of intelligence. He argues that if it were, design intelligence would hold the characteristics of being speculative, existing due to the human capacity to form mental representations of ideas, existing socially as models act as representatives for human imaginings, and its content would be derived from the rules of human perception (Baynes, 1992b). Seery (2017) builds on this position by advocating that modelling, one of the core aspects of design, also consists of an element of critique. This dichotomy between speculation and critique mirrors the two aims of contemporary graphical education whereby creative endeavours could be argued to be a more speculative process in comparison to the critical nature of technical skills.

## Operationalising Designerly Thinking through Conceptual Design

The nature of design in DCG is conceptual with a view towards manufacture. This consideration for manufacture is achieved through the creation of a CAD model of a design solution. The externalisation of the idea, or modelling, is a critical element of the design process. Baynes (1992b) eloquently describes this process of designing through the three actions of imaging, modelling and communicating. He describes how "people use imaging to visualise or 'see in the mind's eye' [and] they communicate about the things they have visualised by means of models" (p.23). He further suggests the significance of models within the ideation stage of the design journey as models allow for communication with the self and with others.

Archer (1992, p.13) discusses the close relationship between the cognitive activities of designing and learning stating that "the design process is a special application of the

learning process". The contemporary position that design can have profound effects on student learning is ubiquitous causing a need for educators who adopt pedagogical approaches underpinned by design tasks to understand the idiosyncrasies pertinent within the implementation of such activities. Perceptually minor details such as the implementation of output constraints could potentially result in the circumvention of the nature of thinking that the design activity was initially employed to elicit.

## Study Aim

The aim of this study was therefore to examine if, by controlling the tools which students utilise to externalise design ideas, the nature of their output and associated learning objectives could be manipulated. If it is possible to manipulate how students engage with design tasks, specifically concerning how and what they think about, educators would be better equipped to target specific learning outcomes. Specifically within DCG, students undertaking the subject utilise CAD in the form of SolidWorks as a design tool. SolidWorks is a parametric modelling tool and therefore a fundamentally different CAD system, CRE8 which is a freeform moulding CAD software, was utilised as a comparative to examine the potential effects each had on student thinking. As well as its educational association, another reason CAD was selected as the modelling medium is that previous research illustrates a link between CAD and creativity in designing (Musta'amal, Norman, Jabor, & Buntat, 2012) and therefore it presents an opportunity to examine how tasks can be aligned with both creative and technical competencies.

## Method
### Participants

The participants for this study (N=15) were selected based on their inclusivity in DCG at post primary level. 13 participants were studying DCG at Higher Level and two were studying the Ordinary Level course. The cohort had a mean age of 15.53 years with a standard deviation of 0.52 years. All participants had previously engaged in a design and technology subject which required the submission of a design portfolio for assessment and this experience suggested a previously developed construct of how the design task included in the study would be carried out.

In order to examine the effect each CAD software had on student thinking, two groups were formed from the research cohort based on their performance in DCG as evidenced through their most resent exam results. This ensured that the ability level of each group as well as the CAD system were controlled allowing for a more valid interpretation of the research findings. The exam contained both a geometric problem solving element and a parametric modelling element. The student's exam results from both sections were calculated and based on their total scores they were stratified between a parametric and non-parametric group so that both groups had near equal average scores. The average result of the non-parametric group was 61.25% and the average of the parametric group was 59.23%. The average result for the entire cohort was 60.3%. Eight students formed the non-parametric group while the remaining seven formed the parametric group.

## CAD Modelling Tools

Parametric modelling in the form of SolidWorks was selected to be one tool the students would use to reflect their current educational curriculum. A freeform surface modelling system called CRE8 was chosen as the comparative as it is a 3D design and moulding program and therefore required a fundamentally different approach to modelling. A Novint Falcon is required in conjunction with CRE8. The device provides haptic feedback to the user allowing them to feel their model and manipulate it through touch providing an additional opposing characteristic to a parametric modelling tool. Figure 1 depicts a student using CRE8 and the Novint Falcon to model an organic geometry. When modelling with CRE8, the user first selects an initial geometry and then deforms it to create the desired geometry. Additional geometries are then created relative to this and there are no explicit dimensioning features. The non-parametric group were allocated CRE8 for this study.



*Figure 1. A participant using CRE8 and the Novint Falcon to model an organic geometry.*

### Pre-study training

All students had previous experience of parametric CAD modelling, engaging with it for ten weeks prior to the study which amounted to ten 70 minute lessons. These lessons focused on skill development and modelling solid geometry. The features examined during this time were extrudes, revolves, sweeps, fillets, and chamfers to both add and subtract material. As no student had experience of the non-parametric CAD system prior to the study, a 20 minute demonstration was delivered to the non-parametric group. During this time the group received an overview of the technology followed by each student experimenting individually with the software and hardware while asking questions to clarify any queries as a group. They then participated in individual modelling tasks requiring them to model an organic geometry allowing for the development of personal constructs such as their own

capability and the capacity of the modelling tool. Upon completion, the parametric and non-parametric groups were reunited for the beginning of a design task. The reason for the significant time difference in the student's exposure to both CAD systems relates to the number of available features in each and the different approaches to modelling solid geometry. As the non-parametric CAD system only contained a small number of independent commands, the required learning time was small.

## Formulating the design task

Doyle (1983) argues that when designing tasks to encourage students to work at a comprehension or understanding level the task must remain ambiguous. The task also needed to be designed to allow for both a parametric modelling solution and for a freeform moulded solution. The concept of a chair was chosen for the task as it would be both familiar yet indistinct and the vague nature of the concept would lend itself to multiple possible solutions from both modelling mediums. The use of a chair as a design stimulus is also commonly used in design research (Buckley, Seery, & Canty, 2017; Goldschmidt & Sever, 2011)

## Implementation

The first stage of the design task required students to conceptualise individual design ideas. The students were provided with paper and sketching equipment. No communication was permitted between students to allow individual thought processes to be captured through their sketches and annotations.  Students were afforded 30 minutes for this activity.

The second stage of the task required students to complete a modelling plan based around Chester's (2007) 'CAD Workbook' as a pedagogical strategy to encourage the development of strategic knowledge in the students which could be utilised in the creation of their models. Students were instructed to create a plan which could be used to guide the modelling of their designs using their allocated CAD software. No explicit form of graphical communication was required allowing students to select the mode of communication they felt was most appropriate. Designs were allowed to be refined during this time but the overall concept had to remain the same. The purpose of this activity was to require the students to consider their designs under the constraints placed on them through their allocated modelling medium. This activity was run for 30 minutes.

The final stage of the task required students to model their designs using their allocated CAD software. Each student was afforded 30 minutes for this activity. This experience was captured using both a visual (screen capture) and verbal protocol.

## Capturing participant responses

Upon completion of the design activity all students were introduced to CRE8 and the Novint Falcon and the parametric group were given the opportunity to explore them through a similar demonstration and modelling exercise as was experienced by the non-parametric group. All students then participated in semi-structured interviews designed to gather feedback on the modelling tools where they were asked about their experiences with them and their perceptions of their uses.

A repertory grid was subsequently implemented to uncover the students' personal constructs related to the modelling tools. This approach was selected to allow for the elicitation of perceptions without researcher bias (Whyte & Bytheway, 1996). When implementing the repertory grids it was decided to include additional modelling mediums which were familiar to the students as comparatives based around Thurstone's (1927) law of comparative judgement. Therefore, sketching, discussion, technical drafting, modelling with rigid materials, and modelling with malleable materials were included. Each modelling medium was evaluated on a number of criteria on a 10-point slider scale (See Table 1). The students completed a questionnaire and the results then automatically populated the repertory grids.

## Findings

The results of the ideation stage of the design task illustrate the different approaches taken by both groups (Figure 2). This was seen initially through the modes of communication used with the entire non-parametric group selecting the medium of sketching with annotations while 28.57% of the parametric group selected technical drafting as the most appropriate medium of communication. These took the form of orthographic, oblique and isometric drawings.

The modelling plans further conveyed these opposing approaches, again seeing the non-parametric group continuing to graphically represent their ideas through sketches while 57.14% of the parametric group now relied on text to create the plans. The remaining students from parametric group, who did choose to graphically represent their ideas, displayed them as an assembly guide.
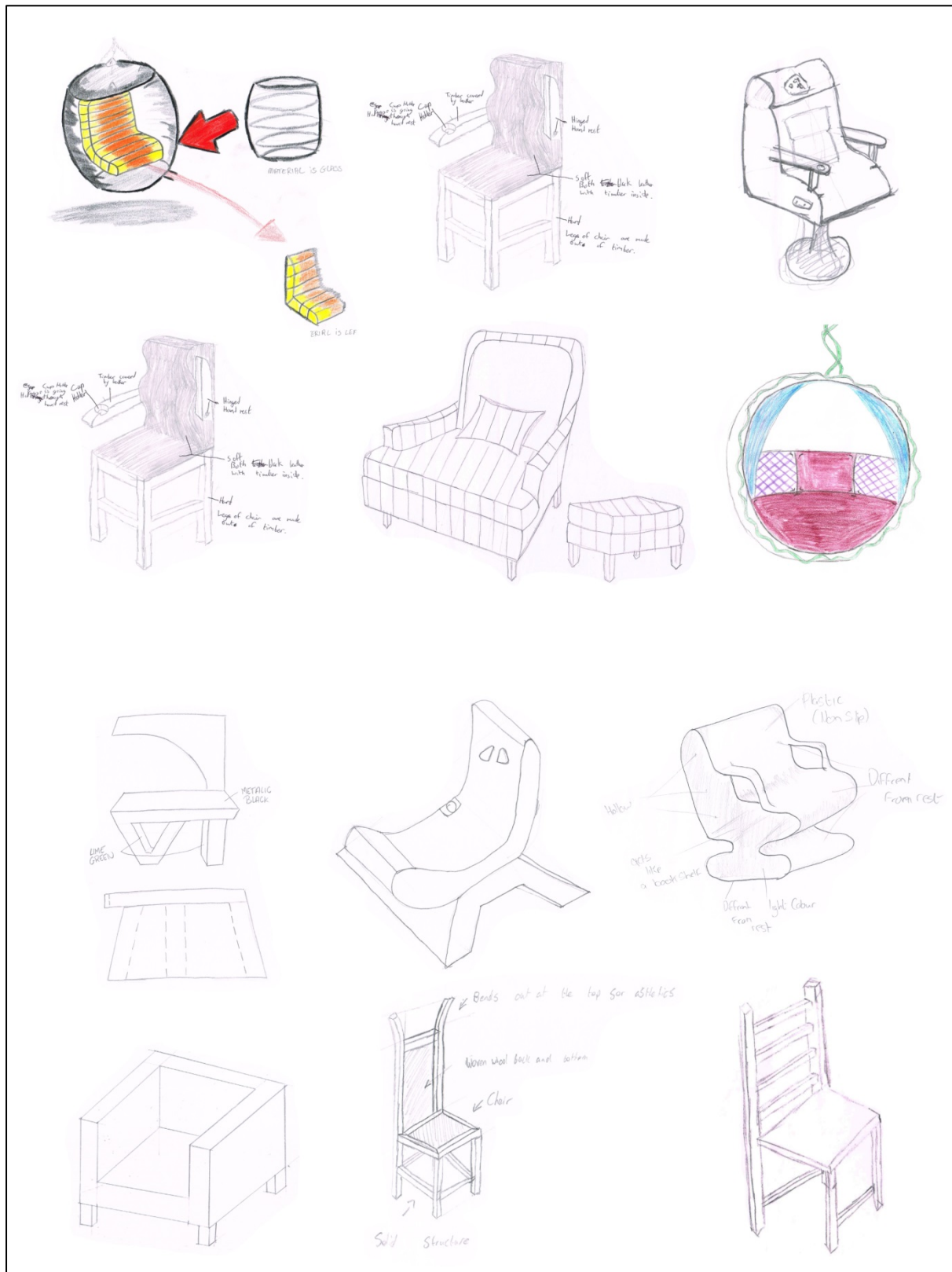
*Figure 2. Sample of ideas from the non-parametric group (top 6) and parametric group (bottom 6).*

A number of themes were illustrated within the students designs (Figure 2). The parametric groups' designs suggested a dictation by a manufacturing process whereas the non-

parametric groups' designs were user focussed. The parametric group designed chairs which were predominantly square in shape. Those that had curves could be modelled by sketching the end view of the chair and extruding it. Reflecting a potential user, the non-parametric group designed chairs that with a more organic form. Three students designed chairs where the primary geometry was a sphere while the remaining students created chairs that were primarily based on curved geometry such as cylinders or they deformed prisms to fit the user.

Further analysis of the designs yielded more insightful findings concerning the influence of each CAD system. In both the conceptual ideas sheets and the modelling plans, the non-parametric group evidenced significantly more depth in their ideas (Figure 3) with more students considering design aspects a greater number of times while the modelling plan activity for both groups evolved into a space where all students viewed their designs in more depth and through more lenses. The only aspect of their designs the parametric group viewed in more frequently was the size of their designs which is posited to be a reflection of the technical nature of parametric driven design.
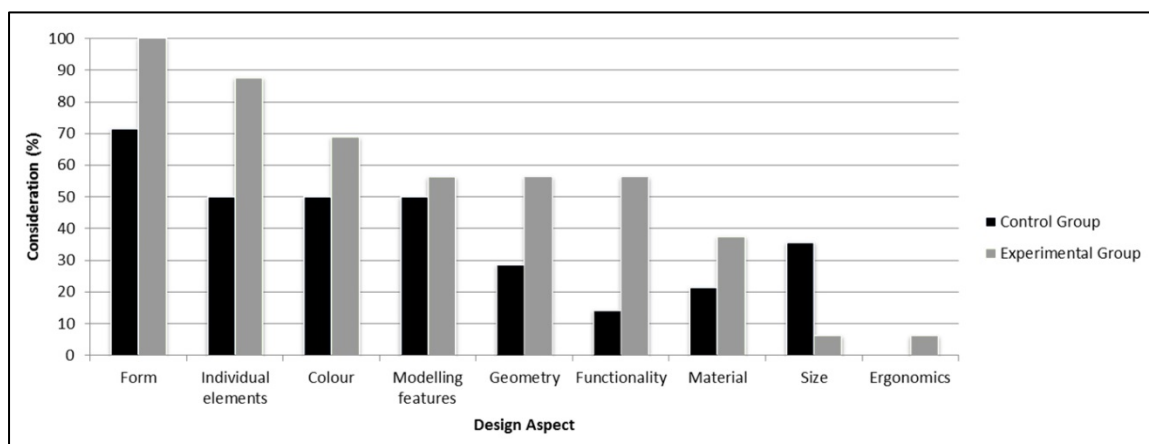


*Figure 3. Design considerations from both the ideation and modelling plan stages.*

During the interviews the students highlighted their perceptions of each CAD system based on their experiences. The parametric approach was commended for its 'variety' (PT03) of features and 'accuracy' (PT03, PT06) however many negative views were held regard how 'linear' (PT09) it was, it's greater learning time and difficulty level, that you had to have 'certain lines' (PT09) [referring to closing contours, fully defining sketches and the use of construction geometry] and you 'couldn't have wild designs' (PT09) that they had to be 'simple enough' (PT09).

The non-parametric approach also had a mixed response. On a positive level it proved to be "fun" (PT01, PT14), "interesting" (PT01, PT14), "easier than SolidWorks" (PT01, PT07) and that 'you do what you want, what you want to see in the end' (PT07). Criticisms of the non-parametric approach centred around inaccuracy, the 'certain amount of shapes your allowed to use' (PT10) and students initially found the Novint Falcon difficult to control.

All students shared the view that they would have liked to be able to use both on their designs and indicated how they would have done so. Some wanted to begin in parametric

modelling to create the initial basic shape and then transfer that model into the non-parametric system to deform it to make it more comfortable, others wanted to start in the non-parametric system to make a moulded starting point which they could dimension and add features to by parametric modelling and more suggested that they were capable of making geometries in both but the copy and paste feature available in the non-parametric system and being able to freely drag geometries would be useful.

The final piece of data gathered was from the repertory grids. Each student indicated their own personal constructs for each modelling tool on a slider scale. The descriptions in the left and right columns indicate the terminology at either end of the scales. For example, 'difficult to learn/develop competency' was at one end of the first scale with 'easy to learn/develop competency' being at the other end. After each student indicated their position on each scale for each modelling tool, average values for each group were calculated. Table 1 shows the mean differences in values between both groups for each of the scales. Following the design activity, the non-parametric group appear to value sketching and modelling with malleable materials more highly than the parametric group while the parametric group in turn value technical drawing and modelling with rigid materials. Both rated the CAD programs and discussions relatively equally. Due to the small sample size, statistical significance testing was not conducted.

*Table 1: Repertory grid showing personal constructs of the parametric and non-parametric groups.*

|  | SolidWorks | Novint Falcon | Sketching | Discussion | Physical Modelling *Rigid Materials* | Physical Modelling *Malleable Materials* | Technical Drawing |  |
|---|---|---|---|---|---|---|---|---|
| Difficult to learn/ develop competency | 0.52* | 0.57* | 0.63 | 0.98 | 0.61 | 0.21* | 0.02 | Easy to learn/ develop competency |
| Tedious to do/use | 0.23 | 0.89 | 0.71 | 0.32* | 1.20 | 1.75* | 1.61 | Enjoyable to do/use |
| Useless | 0.25* | 0.61* | 0.21* | 0.80 | 0.34 | 1.84* | 1.07 | Useful |
| Does not aid in developing understanding of | 1.43 | 0.36 | 0.50* | 0.79 | 0.46 | 0.73* | 1.04 | Aids in developing understanding of |
| Irrelevant | 0.95 | 0.45 | 0.29* | 0.32* | 0.96 | 0.27* | 1.27 | Relevant |
| Complicated | 1.11* | 1.20* | 0.45* | 0.16* | 0.36 | 0.38* | 0.91 | Intuitive |
| Long learning time | 0.39* | 0.14* | 0.23* | 0.16* | 2.29 | 0.57 | 0.11* | Short learning time |
| Unhelpful in communicating | 0.75 | 0.02 | 0.02* | 0.00 | 0.30 | 1.29* | 0.91 | Helpful in communicating ideas |
| Would not use by choice | 1.95 | 0.13* | 0.61 | 0.79 | 0.68 | 0.36* | 1.79 | Would use by choice |

Note. *Indicates higher mean values from the non-parametric group. Scores with no asterisk indicate higher mean scores from the parametric group.

## Discussion

The findings of this study illustrate that both groups had different approaches to this design task. Considering the variables of ability, task, and CAD systems were controlled for, the empirical evidence from this study therefore indicates that the CAD systems likely caused the variance in student approaches. These findings have many parallels to a similar study conducted by Kimbell, Lawler, Stables and Balchin (2002) in which they examined the use of Pro/DESKTOP (PDT) at post-primary level in England. Kimbell et al. (2002) found that students who used PDT designed in a particular way which was inherently associated with PDT, similar to how in this study the use of parametric and non-parametric CAD influenced students design approaches. From a pedagogical perspective this has significant implications as it highlights the impact that strategic task design can have on student learning and how

educators can control variables to influence expected student responses to pedagogical tasks. For graphical education educators specifically, by utilising certain tools teachers can enhance students' creative endeavour or manipulate the same task to be technically orientated. This is important both when considering the aims of graphical education but it can also be applied at an individual student level to address deficits students may have. For example, some students in a cohort may have stronger technical skills and need additional emphasis on creative development while conversely, other students may need to develop higher levels of technical proficiency.

The findings that the parametric group spent more time focusing on the dimensions of their design while the non-parametric group considered all other elements to a greater extent does not necessarily indicate that using CRE8 resulted in a more substantial level of thinking. It does however indicate that overall designs were considered in greater depth. The parametric group may have invested deeply in the consideration of their designs technical specifications whereas the non-parametric group may have examined multiple aspects at a conceptual level. Again, this is a critical implication for educators when designing a task as they may need students to engage with certain aspects of a design task very critically while other aspects, depending on the intended learning outcomes, may only require peripheral consideration.

The results from the repertory grids potentially highlight how the affective domain can be influenced by new experiences. The non-parametric group valued what could be seen as more fluid or conceptual ways of modelling more highly while the parametric group placed more value on technical activities. Unfortunately, similar repertory grids were not carried out prior to the study to identify if this signifies a change in personal constructs but it does provide merit to exploring how educational experiences impact on our value systems and then in turn how these value systems effect our learning. If it is the case that parametric modelling assists in the development of technical values then perhaps a more fluid modelling tool should coincide with this to achieve a balance in adhering to curricular intent. Considering the potential synthesis of multiple modelling tools in practice, the results of this study further indicate the capacity that student have, at least at upper post-primary level, to critically decide the appropriateness of different tool functions for different design stages.

Making decisions pertaining to appropriate modelling tools is a significant skill in relation to design students. The findings from this study clearly illustrated that the students had sufficient capacity to select the appropriate actions to achieve their goals through their identification that a synthesis between both parametric and non-parametric tools would have been the most appropriate way to approach modelling in the design task. Again, this is similar to the study conducted by Kimbell et al. (2002) whereby students identified the capacities of PDT such as its accuracy and its ability to provide a clear visual representation of a design. Considering Crehan et al's (2012) observation that removing explicit design criteria can complement a deep approach to student learning coupled with the capacity to identify an appropriate strategy as evidenced by the students in this study, it is posited that allowing students the capacity to make executive decisions concerning their approaches to design tasks would facilitate their progression and learning within graphical education. A final note relating to giving students more freedom to choose a particular type of CAD

system is that students can find learning parametric CAD quite difficult. This was shown both in this study and in the study conducted by Kimbell et al. (2002). The difficulty in learning parametric CAD was discussed more deeply by Kimbell et al. (2002) and with additional evidence they illustrated how this difficulty can have positive effects on motivation and enthusiasm. Specifically, they acknowledge computer-game culture may have a role in this as with both parametric CAD and computer games, difficulty can be regularly faced however when overcome this can have positive motivational effects. This has pedagogically implications as while it is important to design tasks with reasonable levels of difficulty, the challenge posed by parametric CAD is not inherently bad.

## Conclusion

This paper has presented empirical findings which demonstrate controlling variables associated with student output can affect student responses. A direct consequence of affecting the actions of students is the manipulation of student thinking. Where there is multiple focuses within a curriculum, such as the aims to develop both creative and technical competencies in graphical education, educators can orchestrate tasks which manipulate student outcome to address different intended learning outcomes. It is apparent in this study that parametric modelling resulted in students taking a more technical approach within a design task while freeform moulding allowed students to work more fluidly and promoted comprehensive user centred design. A more comprehensive knowledge of the affordances of modelling tools can empower teachers to be more scientific in their approaches to student learning by facilitating individual student needs. Additionally, the students within this study identified the appropriateness of working outside the constraints of the design task and with students evidencing this cognitive capacity, confidence is given to allowing students more freedom in their own educational decisions. However, while affording students the capacity to make decisions pertinent to their own design journeys, a careful balance must be achieved to ensure such decisions don't ultimately result in the circumvention of the learning outcomes which are at the core of the design task.

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