

The impact of Computer Aided Design and Manufacture (CAD/CAM) on school-based design work

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Abstract

This paper reports the findings of a national survey distributed to Heads of Design and Technology departments, with the aim of identifying the level of CAD capability that currently exists, and the nature of its implementation, within UK schools. It draws on teacher perceptions and conclusions from the study to identify further research that might be undertaken to help clarify the impact CAD/CAM has had on the activity of 'designing' within an educational context.

The role and impact that CAD may have on other aspects of Design and Technology education is described and provides for a more informed discussion on the students' learning experience, particularly where this might be promoted by CAD.

Keywords: CAD, CAM, design, education, model, process

Background

The CAD/CAM in Schools programme, introduced in 1999, has enjoyed increasing success with the number of registered teachers exceeding over 8000 in the last year. The British Educational Communications and Technology Agency (BECTA) identified Design and Technology as the curriculum area with the highest level of substantial use of Information and Communication Technology (ICT) second only to the subject of ICT itself (BECTA, 2004). It is likely that CAD/CAM may be a contributing factor to that increase in provision and in turn had some impact on the activity of 'designing' in a school-based context.

The process of 'designing' in Computer Aided Design (CAD) has been the subject of continued scrutiny, often leading to comparisons between design work undertaken using CAD and that completed without it. In this respect, Kimbell et al (2002) described an inability to achieve the level of effective development on CAD associated with the traditional pencil and paper folio. However, until now, the extent to which CAD has been effectively implemented in school based design is a research question as yet to be objectively measured (Hodgson & Allsop, 2003).

In order to assess the impact CAD/CAM has had on school-based design work it is important to discuss what is meant by the term design and the nature of the activity of 'designing'.

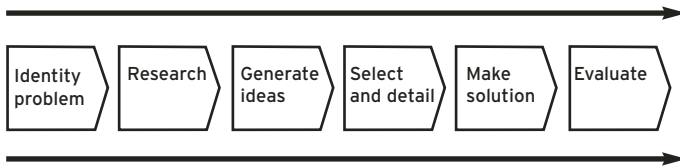
Describing design process

The ability to document and prescribe the process of design activity is desirable as the technological advances conceived within the act of 'designing' shape both our culture and our future (Norman, 2005). Subsequently, a great many attempts have been made to isolate the essence of designing and document it in the form of a generic method that could be applied in all situations. As a result, early models of the design process were described, predominantly, in terms of a linear process often, as a series of ordered and prescribed elements (see Figure 1). However, there is an increasing awareness that designing may not be so easily defined.

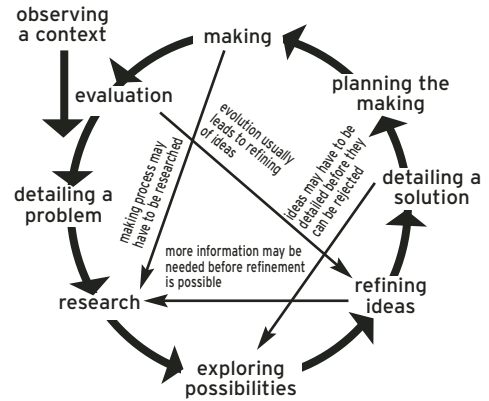
Design is often described as problem centred activity, and that the problems inherent are ill defined and often irresolvable by logical or scientific means. Design problems by their ill definition therefore consist in a state of affairs in which we feel some unease, discrepancy or incompatibility (Norman & Roberts, 1999). It is likely that there are as many ways of solving a 'design problem' as there are designers and it is, therefore, unlikely that a generic process can be formulated or easily described. (Jones, 1970)

As a result, later models often incorporated a high level of generality in an attempt to formulate a generic process. How these models were prescribed or documented is generally a defining characteristic of individual authors and the activity they attempted to reflect. However, these models evolved to form representations of the process that were typically cyclic and encouraged the interaction between aspects of the design problem often derived from earlier linear models.





Representation of the process prescribed by Schools Council 'Design and Craft Education Project' (1972) Kimbell et al (1996)



The GCSE cycle of 'Designing' Kimbell (1986)

Figure 1: Evolution Of Design Process Models

The recent retreat (in research terms) from the systematic and procedural models of designing prescribed in the early 70's literature on design process theory, to a position of greater uncertainty (models which incorporate a high level of generality and iteration) in an attempt to understand how designers come to 'know what they know', has resulted in widespread confusion (Baynes, 1990). Any such confusion may not be desirable if we wish to easily define the activity or process of design.

Irrespective of this confusion, the activity of 'designing' prescribed in design process models typically express a common thread; from that of an inception of an idea, through stages of reflection, to eventual evaluation of a particular outcome (Johnsey 1995, Mawson 2004).

It has been noted that the ability of design to shape both our culture and future means that stakeholders within that culture will seek to gain control. It is, therefore, unsurprising that the two primary areas from which models of designing have emerged are design management and design education (Norman, 2005).

Subsequently, it could be considered that the principal motive for the development of models of the design process was to make possible the teaching and assessing of technology education by imposing order on what is essentially a confused iterative process (Mawson, 2004). It may not be of any great concern, therefore, that designing is not represented too closely within these models, but, that the models represent a guideline or framework by which design activity may be more easily identified.

It is important to acknowledge the fundamental differences between the two contexts identified (design management and education). Therefore, consideration of design activity in education and how this may be described or modelled is useful to this research.

'Designing' in Education; a description of design as an educational activity

In order to better understand an educational perspective it is useful to provide a description of what the activity of designing in an educational context involves.

There are clear differences between the role of design in industry and its role in education. It is apparent that despite 'design activity' (within industrial or 'real' scenarios) being concerned with the attainment of a result, 'design educational activity' is additionally concerned with the development of pupils' knowledge and understanding. This is not to say that the attainment of a particular outcome is necessary to constitute 'designerly' activity but more that what is learnt *through* design is of greater importance than learning *about* design.

While it is accepted that a universal method of design is not widely accepted or applied, Cooke et al (1984) suggest that a suitably constructed framework allows the participant to connect knowledge and skills in a logical way and should be used to guide teacher and pupil endeavour. This may explain why models of design that are adopted by educationalists are not a true reflection of design activity or process that would be typically identified by a practitioner.



It is clear that the manufacture of objects or artefacts can be seen to encourage relevant 'designerly' activity and to promote the relevant capabilities that meets the aims of design and technology education in the National Curriculum.

For example, throughout the attainment targets set out by the National Curriculum for England (DfEE, 1999) there is a suggested underlying framework which notes the importance of the manufacture of products. It is also suggested that the associated practical tasks actively encourage the advancement of knowledge and understanding identified as central to capability in design and technology education (DfEE, 1999).

Such curriculum frameworks need not follow those of industrial design too closely, but can usefully reflect how design activity is used as a 'vehicle for learning' in design and technology education.

It should be noted that the presence of all or many objects or artefacts does not necessarily mean an act of 'designing' was necessarily undertaken (Roberts, 1992). Also, an identical task may result in quite different levels of capability being demonstrated (Kimbell et al, 1990). The presence of an outcome does not, in itself, suggest that learning took place or capability was developed. For similar reasons, we must better understand the contribution that CAD makes to the design process and be careful that its implementation does genuinely bring about change in the awareness and capabilities of the participants that may be regarded as central to capability in design.

The adoption of CAD therefore, to purely reflect industrial practices within an educational context, can be seen as a somewhat naïve application of the technology. It is necessary, instead, to gain a better understanding of CAD in education and the nature of its use and implementation. A survey of CAD use was developed to better understand the learning experience that CAD promotes and in turn its ability to promote or detract from the intrinsic values of 'design and technology' education as a whole.

Developing a National Survey

A pilot survey of approximately 800 accredited trainers for the CAD/CAM in Schools programme identified a range of design, and other activities, that might be developed through the use of CAD, with 3D CAD modelling being identified as the greatest single significant activity. Subsequently,

these findings were used as a basis on which to construct a national survey with the aim of identifying the level of CAD capability that exists and the nature of its implementation. This was then distributed, on behalf of the authors, by the Design and Technology Association (DATA) to heads of Design and Technology departments.

Participants were asked a range of questions directly relating to their current use of CAD and to identify the use of CAD within a typical 'design process' in their schools. They were also asked to offer their perceptions of CAD implementation, identifying the manner in which they felt the technology is best applied and the main advantages of its use. It should be noted that, following the pilot, this survey focussed primarily on the use of 3D CAD modelling tools and does not reflect the use of CAD/CAM that does not exploit such CAD modelling software.

A copy of the questionnaire can be found at; www.cad-cam-in-schools-online-survey.retrocanvas.co.uk

Amongst other techniques the participants were asked to express their opinion by rating agreement or disagreement with a set of attitude statements. Each degree of agreement was given a numerical value on a five point Likert scale. Thus, a total numerical value can be calculated from all the responses and opinions represented quantitatively.



**Initial Survey Results;
Teacher perceptions of 3D CAD modelling
activity occurring within UK schools**

It was apparent that opportunity exists for the use of CAD at all stages of a typical design process (See Figure 2) and that 3D CAD modelling

software was the most significant contributing factor to the use of CAD within education (see Figure 3). It is possible to assume the CAD/CAM in Schools programme is the single most contributing factor to this use as a result of the predominant uptake of Pro/DESKTOP software (see Figure 3).

At what stage(s) does the use of CAD occur in a typical 'design process' within your department?

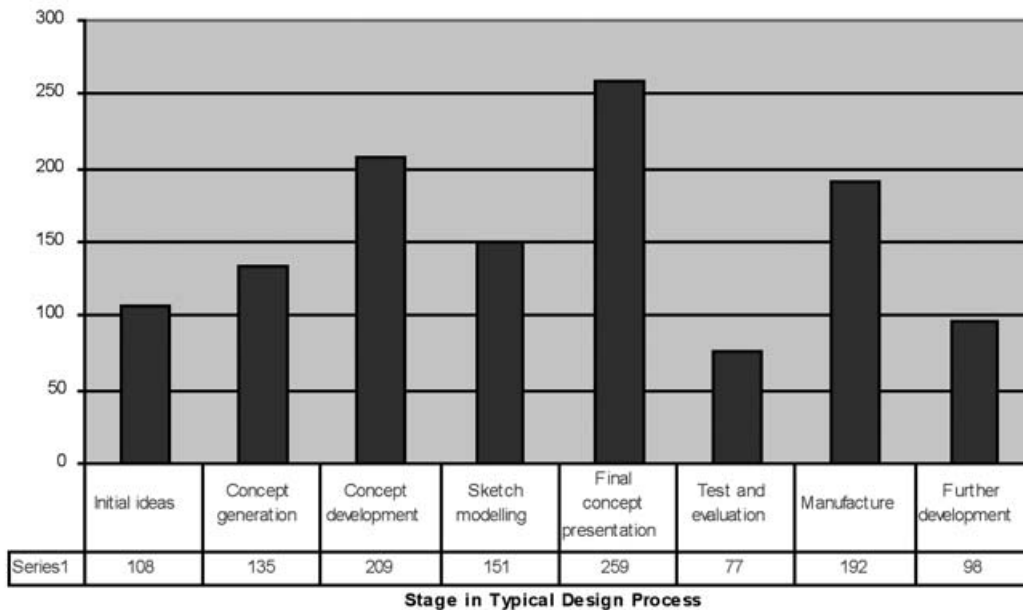


Figure 2: Stages of a typical design process within which CAD is utilised

Which of the following 3D software packages are currently used within your department?

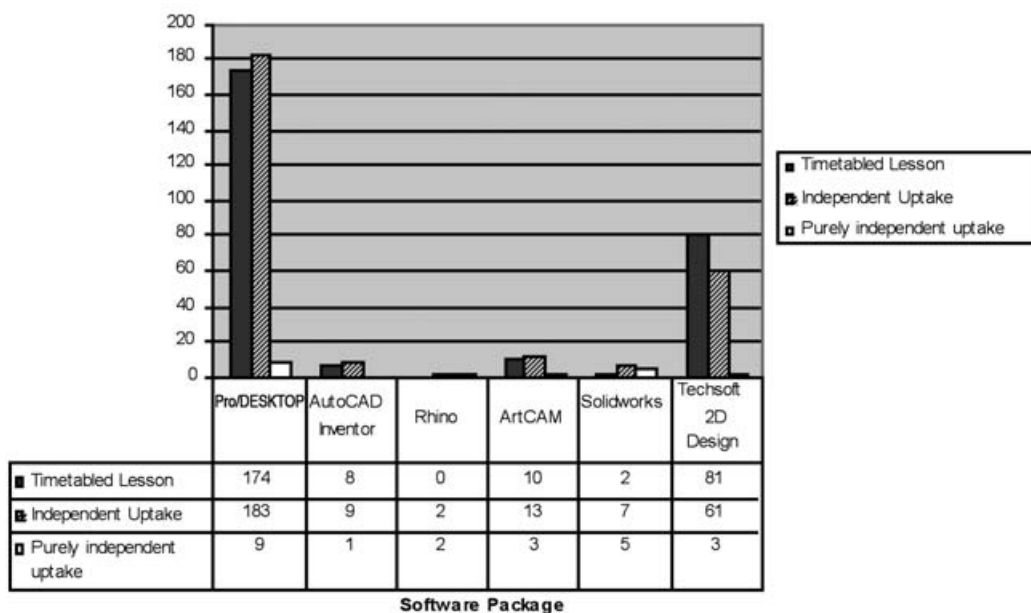


Figure 3: 3D modelling software currently used within UK schools



Student CAD capability

As many as 89% of respondents noted that students were able to alter their design ideas in CAD. Likewise, 75% noted that students felt competent enough to use CAD as a development tool through which modifications could occur. This indirectly supported the belief that some design development activity could occur within a virtual environment (see Figure 4). It was also felt (by 75% of respondents) that the CAD models produced as a result of this modelling activity accurately reflected the students original design ideas or intent. It is possible to assume, therefore, that teachers perceive students to have the necessary skills to model their design ideas effectively in CAD. However, the extent to which the activity of ‘designing’ occurs within, or by using CAD to encourage this activity received a more confused response.

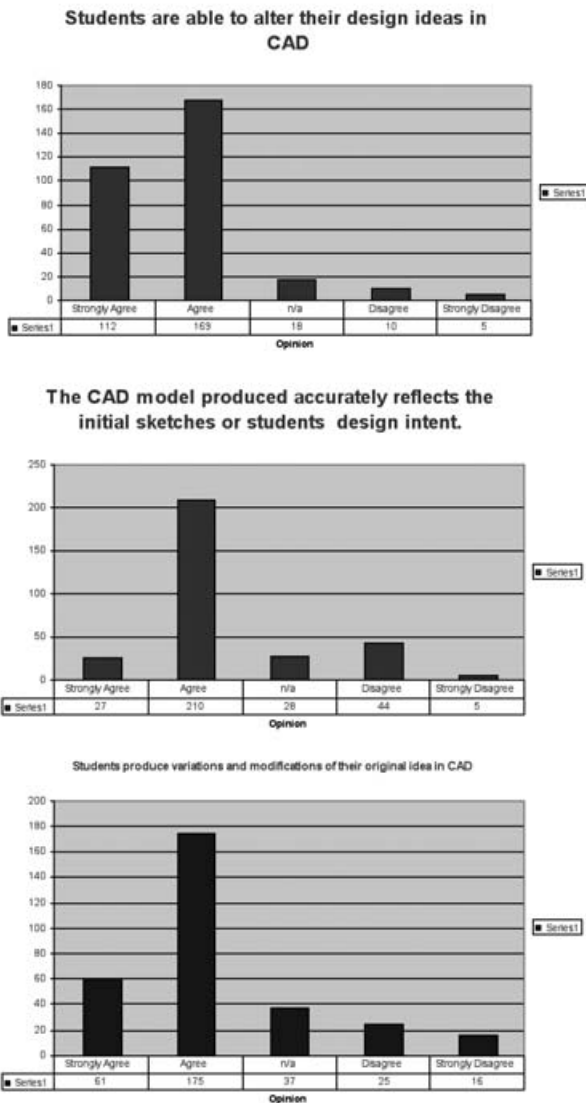


Figure 4: Teachers' perceptions of students' capability to use CAD as a design tool

Students completely design their idea before they model it in CAD

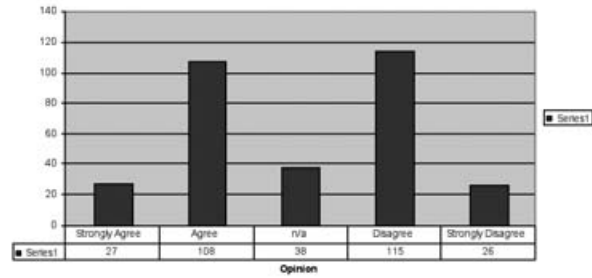


Figure 5: Teachers' perceptions of students' ability to completely design their idea prior to any involvement in CAD

For example, whilst over 78% of teachers identified their students' ability to make a change to a design within a virtual environment, a less obvious distinction could be made respondents (42%) indicated that the design was complete before it was modelled in CAD (see Figure 5). The ability to modify designs and create iterations using CAD is one of its great strengths and, although acknowledged, it must be of some concern if it is not well exploited.

The issues this raises will need to be examined in more detail before any final conclusions about the role of CAD in designing can be drawn.

The Impact of CAD on workshop activity

In order to identify if CAD is shifting the emphasis of activity within ‘design and make tasks’, participants were asked to observe if they felt the use of CAD had lessened the need for associated workshop activity. Participants were asked to identify if experiences that typically occurred in the workshop, such as simulating mechanisms, perceiving the form of design ideas and checking if component parts fit together, had occurred previously as a result of CAD.

Just over half of the respondents agreed, or strongly agreed, that evaluation of the students designs within a context, had occurred as a result of CAD prior to workshop activity.

As many as 62% noted that CAD was used to simulate elements of the design idea and 64% noted CAD aided perception of size form and fit prior to the start of workshop activity.



Whilst there was some consensus (see Figures 6, 7, 8, and 9) that activity previously believed to be undertaken in workshops was taking place in CAD, a far less obvious distinction can be made when the question is asked more directly. Over 33% of respondents noted that they felt CAD had failed to directly reduce the time required for workshop activity (see Figure 10).

CAD was used to visualise the design in context

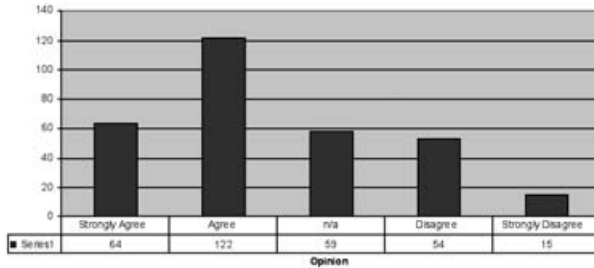


Figure 6

CAD was used to aid the perception of size/form. (e.g. to check parts fitted together correctly)

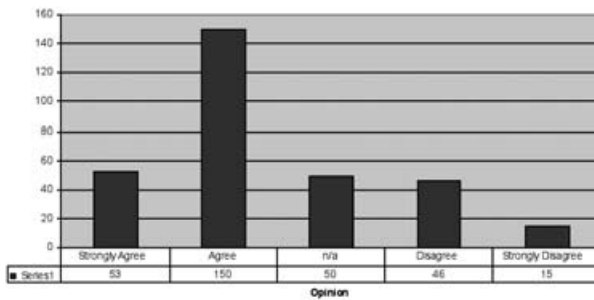


Figure 7

CAD was used to simulate the design idea

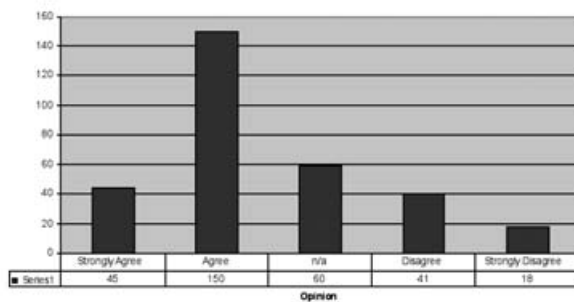


Figure 8

Students use the CAD model to test or evaluate design ideas. (e.g. animate mechanisms)

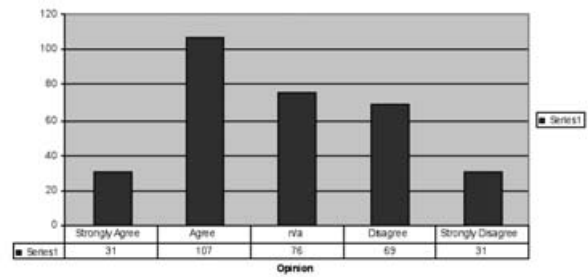


Figure 9

CAD Modelling reduces the time required for workshop modelling

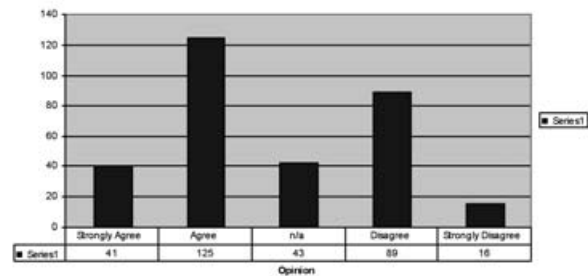


Figure 10

Likewise, 46% of the participants recognised that physical models still formed the basis of submissions, although interestingly, nearly 36% used CAD models for submission (see Figure 11) suggesting a change in traditional assessment procedures within Design and Technology education. Although large support was demonstrated for the submission of CAD models rather than physical models, no distinction was made (within the survey) concerning the extent to which these models reflected design development as opposed to a single final prototype/design. This is clearly another area for further investigation.

CAD models were submitted rather than physical

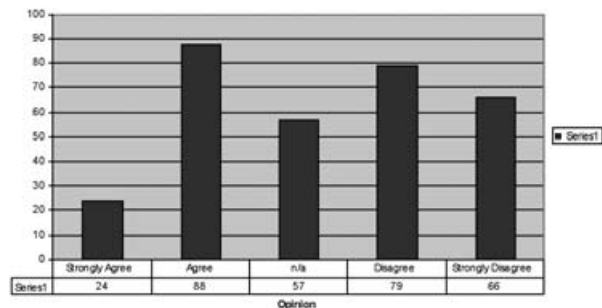


Figure 11



Also, when asked their opinions about which medium they felt best reflected students' design ideas, only 8% felt that students design ideas were best represented in workshop models. About 24% identified CAD with the most (33%) identifying sketches as the best ways of representing designs (see Figure 12).

In my opinion students designs are best represented in:

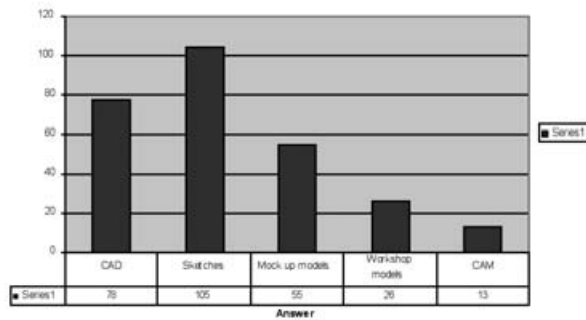


Figure 12

It is clear that the potential for CAD to impact workshop activity has been noted by participant responses showing a clear support for activities (often associated with design realisation) occurring in CAD prior to the commencement of workshop activity. It is interesting that, despite this extensive activity, the use of CAD failed to reduce the time required within the workshop. For example, it would be expected that an increased amount of realisation activity prior to the commencement of workshop activity (in this instance within CAD) would have lessened the time required within the workshop, as arguably students' design intent should be better realised. There is a need to question the extent to which these CAD activities effectively support designing and the development of design ideas. Is this as a result of an inappropriate use of CAD or, is CAD identifying possibilities for development that would not normally have been considered? This is to be the subject of further on-going investigation at Loughborough University.

The role of CAD in design

The use of CAD as a means of generating various outputs is predominant. For example, when teachers were asked what they felt the predominant use of CAD was within the classroom there was clear emphasis on outputs such as rendering/presentation and aid to manufacture in the form of CNC generated models.

This poses further questions about the extent to which CAD is being effectively utilised across the design process. As identified earlier the presence of artefacts or objects (in this instance the use of CAD as an output) does not necessarily denote that a 'designerly' act has been undertaken within an educational context. There is evidence of clear potential for the use of CAD within design, and also to present design but it may be of some concern that emphasis is placed on the latter.

Please put these statements of activity in order of the frequency that they occur within your department

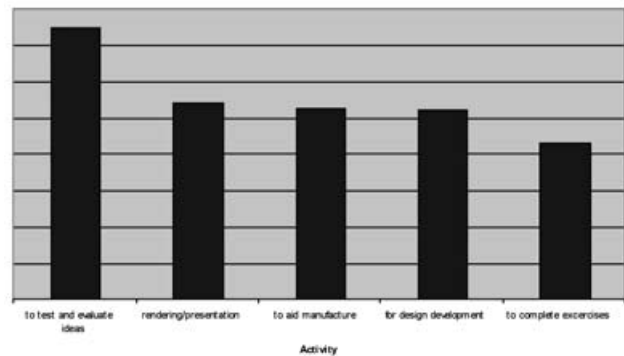


Figure 13

This view is also supported by identifying that 73% of students were willing to annotate around CAD images within folios, but only 29% were willing to sketch over these print outs within a designing activity.

Students annotate CAD images in folios

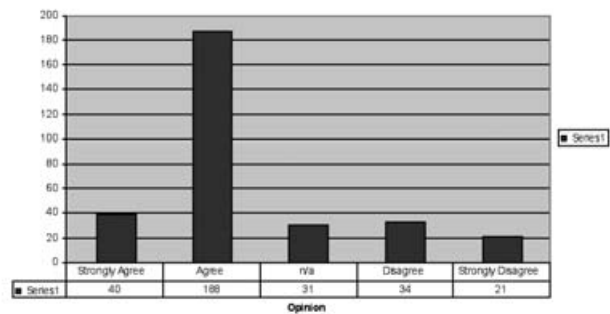


Figure 14

This preservation of 'precious' images serves to support the notion that CAD is utilised significantly as a means to an end in its own right but not directly to, say, modify design ideas and in turn to encourage the advancement of knowledge and understanding that should be developed through the activity of 'designing'.



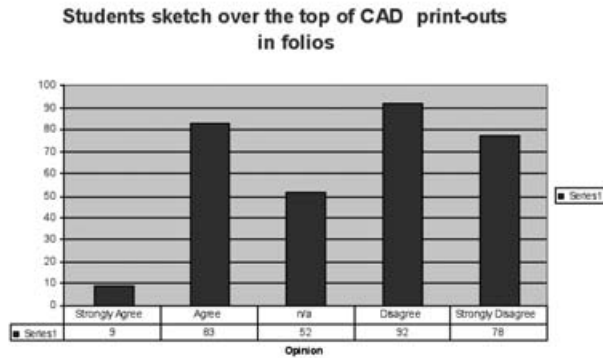


Figure 15

Summary

These initial findings from the survey have identified some awareness of the great potential for CAD to be a part of design development in addition to being a means of providing design output. Teachers believed that many of the activities associated with project-based design could be, and were, undertaken using CAD technology. There is also evidence to suggest the successful adoption of CAD for post processes and outputs but the evidence to suggest that the activity of 'designing' is currently occurring within CAD is, as yet, inconclusive. The respondents to the survey may be seen as 'CAD enthusiasts', yet many responses imply a naïve application of the technology. Subsequently, the impact of CAD on designing and the associated learning experience may, at this stage, be relatively under acknowledged.

It is clear that a better understanding of the learning experience that CAD particularly promotes and the activities which allow for its involvement in the act of designing should be encouraged, in order to promote the learning experiences identified within the national curriculum.

The data recorded needs to be further scrutinised to allow for a more informed discussion about issues raised within this paper and the research objective as a whole. The survey has raised a number of issues to be pursued more directly with teachers in schools. These include:

- the extent to which CAD is replacing or reducing the emphasis on other workshop activity, and the extent to which CAD models are being submitted for assessment;
- the extent to which genuine design activity occurs in CAD and its direct impact on physical modelling undertaken in workshop activity;

- identifying a clearer distinction of the impact of CAD by considering if an ability to design in CAD is considered to be an alternative, or more effective, means of promoting the same learning experience as that which is normally associated with more 'traditional' workshop activity.

It is also considered important to further support the data collected with relevant involvement of schools who make less frequent use of CAD in their design work.

Despite any limitations imposed by the survey this initial analysis should form the basis of more informed further research and the development of a clearer understanding of the role of CAD within Design and Technology education.

References

Baynes, K. (1990), 'Defining a Design Dimension of the Curriculum'. In: D. Thistlewood, ed, *Issues in Design Education*. UK: Longman, 51-63

BECTA. (2004), 'The Impact of Information and Communication Technologies on Pupil Learning and Attainment'

Available at:
www.becta.org.uk/research/impact22004

Cooke, P., Corbett, J., Pugh, S. and Weightman, D. (1984), *A Guide to Design for Production*. London: Institute of Production Engineers

Department for Education and Employment (DFEE). (1999), *Design and Technology: The National Curriculum for England*. London: Department for Education and Employment (DfEE) and the Qualifications and Curriculum Authority (QCA)

Hodgson, T. and Allsop, C. (2003), 'Beyond Pro/DESKTOP Computer Aided Design (CAD): the transfer of CAD-based design modelling skills from schools to Higher Education', In: Norman, E. and Spendlove, D. *Design Matters*; Proceedings of the DATA International Research Conference 2003, 45-49

Johnsey, R. (1995), 'The Design Process - Does it exist?' in *The International Journal of Technology and Design Education*, 5, 199-217

Jones, J.C. (1970), *Design Methods - Seeds of Human Futures*. Bath: The Pitman Press



Kimbell, R. (1986), *GCSE Craft and Design and Technology; A guide for Teachers*, Milton Keynes, Secondary Examinations Council and Open University

Kimbell, R., Lawler, T., Stables, K. and Balchin, T. (2002), 'Pro/DESKTOP in Schools: A pilot research study'. *The Journal of Design and Technology*, 7(1), pp. 29-33.

Kimbell, R., Stables, K. and Green, R. (1996), *Understanding Practice in Design and Technology*, Buckingham, Open University Press

Kimbell, R., Stables, K., Wheeler, T., Wosniak, A. and Kelly, V. (1991), *The Assessment of Performance in Design and Technology; The final report of the APU design and technology project 1985-1991*, London: Schools Examinations and Assessment Council

Mawson, B. (2004), 'Beyond 'The Design Process': An Alternative Pedagogy for Technology Education', *International Journal of Technology and Design Education*, 13, 117-128

Norman, E. and Roberts, P. (1999), 'Models of Design and Technology and their Significance for Research and Curriculum Development', *Journal of Design and Technology Education*, 4, 2, 124-131

Roberts, P. (1992), 'Of models, modelling and design: an applied philosophical enquiry'. *The Language of Designing: Occasional Paper No. 1*. UK: Loughborough University of Technology, 33-43



Appendix i)

Survey data collected but not directly referenced in this paper

List of Figures

Figure No.	Description
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17	CAD use in other curriculum areas
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20	Teachers' perceptions of students' ability to produce working drawings to aid manufacture
21	Teachers' perceptions of students' ability to produce moulds using CNC equipment from which to make other parts
22	Teachers' perceptions of students' ability to use a CAD model to test or evaluate design ideas
23	Teachers' perceptions of students' increased quality of work as a result of using CAD
24	Teachers' perceptions of students who produce one CAD model after preliminary drawings or sketches
25	Teachers' perceptions of students' ability to model a range of components and assemble them in 3D CAD
26	Teachers' perceptions of students' ability to produce foam CNC models or similar to visualise early designs.
27	Teachers' perceptions of students' ability to alter 3D CAD images in graphics packages
28	Teachers' perceptions of students' ability to use a combination of CAD images and sketches to develop ideas



Please describe how you feel CAD is best taught in schools by prioritising these statements;

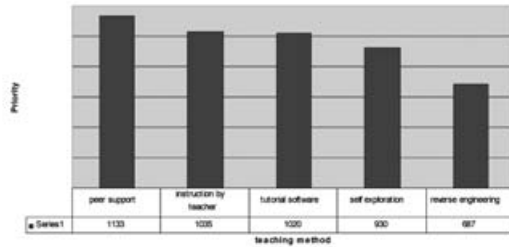


Figure 16

As far as you are aware, has CAD been utilised in any other curriculum areas within your school?

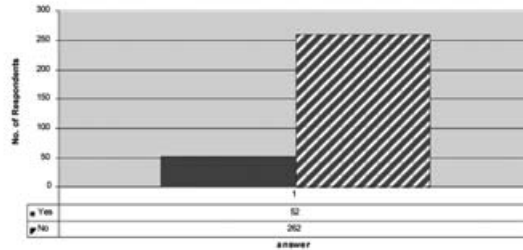


Figure 17

What percentage of timetabled D&T lessons are devoted to CAD tuition?

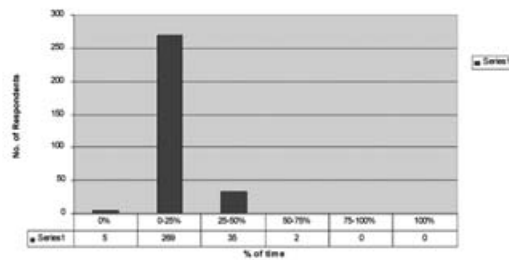


Figure 18

Students re-design in CAD as a result of CNC/RP manufacture

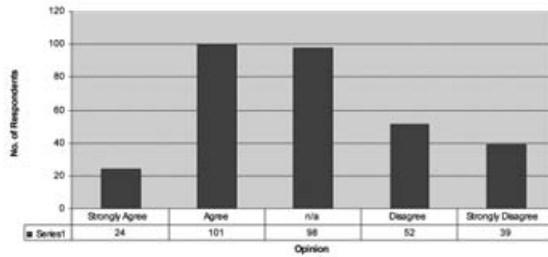


Figure 19

Students produce working drawings from CAD to aid workshop activity

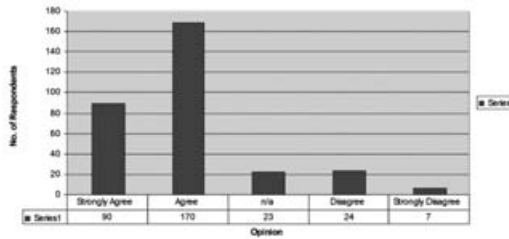


Figure 20

Students produce moulds using CNC equipment from which to make other parts.

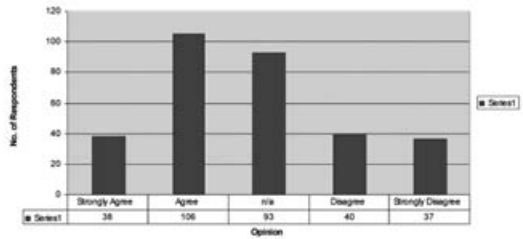


Figure 21



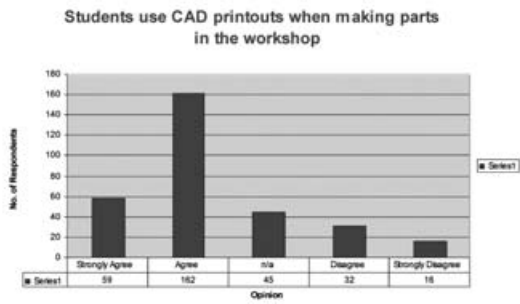


Figure 22

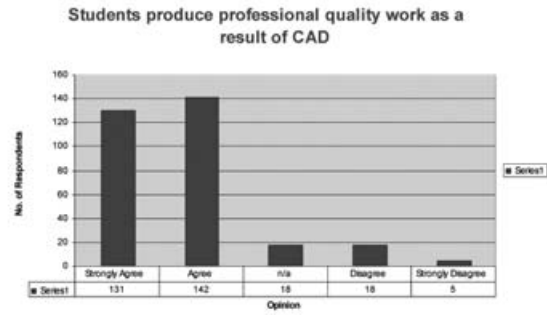


Figure 23

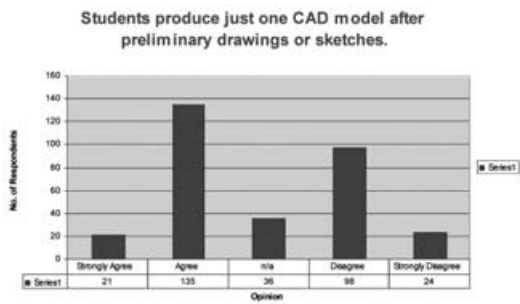


Figure 24

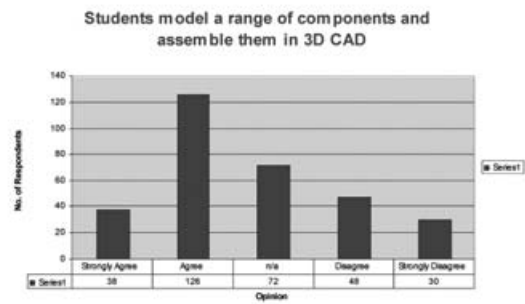


Figure 25

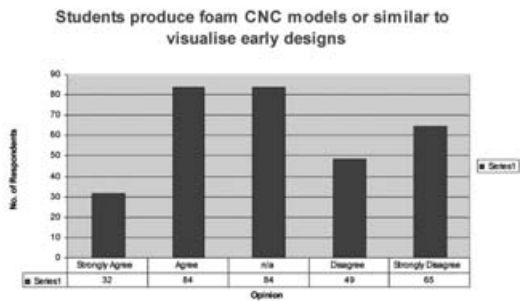


Figure 26

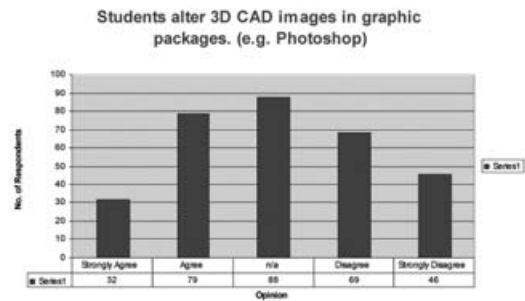


Figure 27

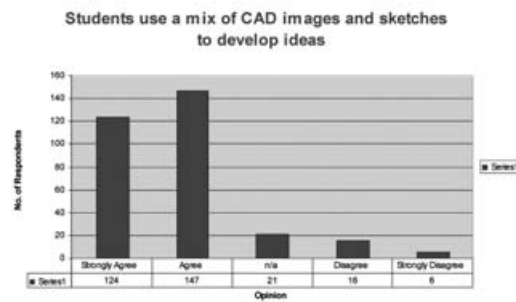


Figure 28

