The development of three-dimensional Computer Aided Design (CAD) modelling strategies and an investigation into their impact on novice users

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THE DEVELOPMENT OF THREE-DIMENSIONAL COMPUTER AIDED DESIGN (CAD) MODELLING STRATEGIES AND AN INVESTIGATION INTO THEIR IMPACT ON NOVICE USERS

BY

CLARE VICTORIA PATRICIA ALLSOP B.A. (Hons.)

A Doctoral Thesis
submitted in partial fulfilment of the requirements for
the award of

Doctor of Philosophy
of Loughborough University
(22nd September 2009)

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<tr>
<td>2D</td>
<td>Two-Dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three-Dimensional</td>
</tr>
<tr>
<td>ARCS</td>
<td>Attention, Relevance, Confidence, Satisfaction</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CAI</td>
<td>Computer Aided Instruction</td>
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<td>CAL</td>
<td>Computer Aided Learning</td>
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<tr>
<td>CAM</td>
<td>Computer Aided Manufacturing</td>
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<tr>
<td>CD-ROM</td>
<td>Compact Disc, Read-Only-Memory</td>
</tr>
<tr>
<td>CMS</td>
<td>CAD Modelling Strategies</td>
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<tr>
<td>CMSS material</td>
<td>CAD Modelling Strategies Support material</td>
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<tr>
<td>CNC</td>
<td>Computer Numerically Controlled</td>
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<td>DATA</td>
<td>Design and Technology Association</td>
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<td>DVD</td>
<td>Digital Video Disc</td>
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<td>ELT</td>
<td>Experiential Learning Theory</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>GPS</td>
<td>Global Positioning Satellite</td>
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<tr>
<td>IT</td>
<td>Information Technology</td>
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<td>ITT</td>
<td>Initial Teacher Trainer</td>
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<td>KS4</td>
<td>Key Stage 4</td>
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<tr>
<td>LEA</td>
<td>Local Education Authority</td>
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<tr>
<td>LMS</td>
<td>Learning Management System</td>
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<tr>
<td>NURBS</td>
<td>Non-Uniform Rational B-Spline</td>
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<tr>
<td>OPAC</td>
<td>Online Public Access Catalogue</td>
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<tr>
<td>PHP</td>
<td>PHP Hypertext Pre-processor</td>
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<tr>
<td>PTC</td>
<td>Parametric Technology Cooperation</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
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<tr>
<td>.STL</td>
<td>Stereolithography (file)</td>
</tr>
<tr>
<td>TIP</td>
<td>Theory Into Practice</td>
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<tr>
<td>VR</td>
<td>Virtual Reality</td>
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DECLARATION OF ORIGINALITY

[SUBSTITUTE PAGE]
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ABSTRACT
Ph.D.

THE DEVELOPMENT OF THREE-DIMENSIONAL COMPUTER AIDED DESIGN (CAD) MODELLING STRATEGIES AND AN INVESTIGATION INTO THEIR IMPACT ON NOVICE USERS

Clare Victoria Patricia Allsop

Computer Aided Design (CAD) is a tremendously powerful tool within the design industry, yet when used inappropriately, can be a hindrance to product designers. Employing ineffective CAD modelling strategies (CMS) can lead to increased project costs as a result of an unnecessary amount of time being spent making design changes to the product. However, when CMS are implemented effectively, it has been shown that novice CAD users can not only create an accurate three-dimensional (3D) representation of a product, but are able to make key design changes quickly and effectively (a skill often associated with 'practiced' CAD users). The submission detailed herein documents the development of 3D CAD modelling strategies and the investigation into their impact on novice users.

The submission has been split into eleven chapters. The subject is introduced in Chapter One, where the background and structure of the research is considered, as well as the implications of lack of CAD experience for novice CAD users. Some initial research aims were generated, which are examined in the ‘Exploratory Study’ detailed in Chapter Two. This includes an exploratory review of literature together with details of the initial studies involving CAD users, where it was found that there were potential benefits of communicating CMS to novice CAD users. Having examined the prior art in the field, a theme emerges regarding the benefits of communicating CMS to product designers and focused research aims are presented.

The research methodology is considered in Chapter Three, which outlines the databases built to manage the periodic review of literature, to ensure that methodologies were in place to draw meaningful results from the data, both qualitative and quantitative. The pilot study, used to understand how designers implemented strategies when modelling on CAD is discussed in Chapter Four, which lead to the definition of the content of the CAD Modelling Strategies Support (CMSS) material in Chapter Five. Following this, a systematic review of literature on the subject of teaching and learning is discussed in Chapter Six, including pedagogical issues such as the Experiential Learning Theory and visualisation, where a blended learning approach was identified as being the most appropriate method with which to present the CMSS material.

The CMSS material was then piloted a number of times within the ‘Pilot Study Two’ phase detailed in Chapter Seven. The final CMSS material is then outlined in Chapter Eight, which was later evaluated against the emergent theme, as documented in Chapter Nine. The discussion continues in Chapter Ten where it was found that the participants exposed to the CMSS material had used a more effective strategy to model a product on CAD than those who did not use the material (the Control Group). This resulted in them being able to make key design changes to their models in approximately half the time of the Control Group. It was found that the CMSS material produced competent CAD users who could easily make design changes to their models, which inferred implications on the teaching and learning of CAD. Overall conclusions and recommendations relating to the research are drawn in Chapter Eleven that, again, bear direct relevance to how product designers learn to use CAD.
Structure of thesis:

Chapter One
Introduction to research

Chapter Two
Initial studies
Emergent theme

Chapter Three
Research methods

Chapter Four
Contributing factors to the selection of a CMS

Chapters Five & Seven
Development of draft CMSS material

Chapter Eight
Final CMSS material

Chapter Nine
Testing of CMSS material

Chapter Ten
Discussion

Chapter Eleven
Conclusion
ACKNOWLEDGEMENTS

Firstly, thank you to Loughborough University for developing my skills in Industrial Design and for all the tutors in the department who have offered developmental and constructive advice willingly and openly. In particular, I would like to thank my supervisor Tony Hodgson, who despite being tremendously busy, was always willing to make time for meetings, read through countless drafts and offer a huge amount of support. Thank you too to all of the participants who took part in the research.

I would like to thank my mother and father for encouraging me to develop a subject that I enjoy, for always supporting me and giving me sound advice. I would also like to thank Rhiad (especially for programming the CMSS material), Beccy, Rhodes and Ed for all that they did to help me along the way.
1 INTRODUCTION

Overview: This chapter provides an overview of the background of the research and considers the positioning of the research in the field, the motivations for undertaking the work, the scope of the work and the structure of the research. Initial research aims are presented, which are later explored in Chapter Two.

1.1 Overview of the research area

Design encompasses many different fields, which can be split into further subcategories, as can be seen in Figure 1.

![Design Diagram](image.png)

**Figure 1: An interpretation of the scope of design**
This research is focused on the area of Product Design/Industrial Design, as indicated in Figure 1. Although Product Design and Industrial Design are very similar in many respects, it is important to note that Industrial Design is a relatively new term and has transpired as a result of designers paying particular attention to the quality and aesthetics of products at the beginning of the 20th Century [Feill & Feill 1999:6-7]. Today, the two disciplines appear to overlap in many respects, so the research concentrates on designers in both categories who make use of CAD, hereafter known simply as ‘product designers’.

CAD has become an indispensable tool within the design world [Booker 2002] and is widely available in schools and colleges [Norman et al. 1995:94, Hodgson & Allsop 2003], where it is estimated that more young people in the UK are making use of 3D CAD than in the rest of the world put together [www.cadinschools.org 2006]. For trainee product designers, CAD has therefore become a key aspect of their education. Potentially, product designers can exploit CAD at the early conceptualisation stage of a design, right through to manufacturing [McMahon & Browne 1998:15], NC programming applications [Beckert 1997] and reverse engineering. CAD allows for technical drawings to be produced up to ten times as quickly as drawing manually [Yarwood 2005:296] and allows for parts to be modified without having to redraw [Ibid]. Through the use of CAD, the need to store physical copies of drawings has been negated somewhat as they can be saved electronically [Ibid] and can therefore be sent via the Internet [Ibid], ensuring that designs can be sent for approval by the client immediately.

However, as with any technology, there exist disadvantages, as well as advantages, for designers using CAD, which can be seen in Table 1.
Examples of advantages of using CAD | Examples of disadvantages of using CAD
--- | ---
Cuts time to market for products [Booker 2002, Rawlins 2002] by allowing for concurrent engineering through the ability to share files [Ulrich & Eppinger 2000], which decreases changes to the product at the last minute | Users may not have a thorough understanding of the system [Fischer: 1991:16], which could potentially lead to the user creating the model ineffectively [Bhavnani & John 1997]
Ability to exploit CAD models at many stages whilst designing - from initial conceptualisation through to rapid prototyping [McMahon & Browne 1998] | Users may find it hard to make design changes to their CAD model if they have not modelled the product effectively
Ability to rapid prototype products [Ulrich & Eppinger 2000] | CAD could hinder creativity [Lawson 2002] if the user is driven by the CAD package rather than their design ideas (e.g. through a lack of experience)
Aids visualisation [Paterson 2003, Booker 2002] | For a novice CAD user, modelling on CAD could take longer than sketching during the initial conceptual stage of the design process

Table 1: Advantages and disadvantages of using CAD

To reduce the time to market for products, product designers (both within industry and educational institutions) employ design processes [Dieter & Schmidt 2009, Cross 2000, Ulrich & Eppinger 2000, Stanton 1998, Lawson 1997, Pugh 1991, Hollins & Pugh 1990, Suh 1990]. These ‘processes’ help to ensure that key deadlines are met and that the end result is delivered as successfully and as timely as possible. In order to illustrate where CAD can be used in a ‘typical’ design process, Ulrich & Eppinger’s [2000] ‘Generic Product Development Process’ has been used [refer to Figure 2]. It must be noted that it would be wrong to suggest that this is a universal approach used by all companies and designers, as there are have been many attempts at describing this process [Lenart & Maher 1996]. As can be seen, CAD can be used extensively within the ‘design’ phase of the ‘Generic Product Development Process’ [Ibid] (the area indicated by the grey box).
Examples of how CAD can be used within the ‘design’ aspect of the product development process can be seen in Table 2.  

---

1 The ‘Design aspect’ was used as an example because this is where the research is focused.
<table>
<thead>
<tr>
<th>Section</th>
<th>Process</th>
<th>Examples of how CAD can be used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept development</td>
<td>Investigate feasibility of product concepts</td>
<td>Generate a number ‘rough’ CAD concepts</td>
</tr>
<tr>
<td></td>
<td>Develop industrial design concepts</td>
<td>Develop ‘rough’ concepts</td>
</tr>
<tr>
<td></td>
<td>Build and test experimental prototypes</td>
<td>Use CAD model(s) to generate rapid prototypes</td>
</tr>
<tr>
<td>System-level design</td>
<td>Generate alternative product architectures</td>
<td>Use CAD to define alternative product architectures</td>
</tr>
<tr>
<td></td>
<td>Define major sub-systems and interfaces</td>
<td>Use CAD model(s) to define sizes, functionality</td>
</tr>
<tr>
<td></td>
<td>Refine industrial design</td>
<td>Refine CAD model(s)</td>
</tr>
<tr>
<td>Detail design</td>
<td>Define part geometry</td>
<td>Define geometry on CAD model(s)</td>
</tr>
<tr>
<td></td>
<td>Choose materials</td>
<td>Select material properties on CAD model(s)</td>
</tr>
<tr>
<td></td>
<td>Assign tolerances</td>
<td>Assign tolerances on CAD model(s)</td>
</tr>
<tr>
<td></td>
<td>Complete industrial design control documentation</td>
<td>Generate engineering drawings from CAD model(s)</td>
</tr>
<tr>
<td>Testing and refinement</td>
<td>Reliability testing</td>
<td>Use the CAD system to perform diagnostic tests on CAD model(s)</td>
</tr>
<tr>
<td></td>
<td>Life testing</td>
<td>SAMMIE CAD</td>
</tr>
<tr>
<td></td>
<td>Performance testing</td>
<td>Use the CAD system to perform diagnostic tests on CAD model(s)</td>
</tr>
<tr>
<td></td>
<td>Obtain regulatory approvals</td>
<td>Use CAD model(s) to present concept and obtain approval</td>
</tr>
<tr>
<td></td>
<td>Implement design changes</td>
<td>Refine CAD model(s)</td>
</tr>
<tr>
<td>Production</td>
<td>Evaluate early production output</td>
<td>Use CAD model(s) to generate rapid prototype(s) to evaluate concept</td>
</tr>
</tbody>
</table>

Table 2: Examples of how CAD can be used in the ‘design’ aspect of ‘The Generic Product Development Process’ [Ulrich & Eppinger 2000:16]

It is clear that CAD could be used within almost all stages of the ‘design’ aspect of the product development process and is therefore a key tool within the design industry for both generating and modifying designs.

However, as a graduate of Industrial Design and Technology at Loughborough University (and having used various CAD packages throughout the degree), it was clear
that there existed a specific gap in knowledge in the area of strategic use of CAD. For example, as part of the advanced CAD module on the Industrial Design and Technology Degree, the researcher reverse engineered a Dyson vacuum cleaner as part of a team project. The end result was a realistic looking representation of the Dyson vacuum cleaner, as can be seen in Figure 3.

![Dyson Vacuum Cleaner](image)

**Figure 3: Dyson vacuum cleaner [Allsop, Irvine & Wall 2002]**

Due to the collaborative nature of the group work, a number of different strategies had been used to generate the parts, which, when assembling the model from a number of different part files did not prove to be problematic. However, when asked to modify a key dimension, such as the width of the product, the assembly model generated a
significant number of errors, many of which were unrecoverable. If this were an example from industry, where a client had asked for a key aspect to be modified, the implications would be dire in terms of time and cost, in that the model would have to have been completely rebuilt. Clearly, this model could have been generated using different, more effective strategies that would allow the designer(s) to make key design changes to the model easily, whilst continuing to capture a similar level of detail in the design. This is where this doctoral research originated. Specifically, the area that was felt to be lacking was teaching novice CAD users to employ effective strategies in order to become more competent CAD users who can redesign their CAD models.

1.2 Overall aim of the research

Therefore the overall aim of the research was to develop effective CAD Modelling Strategies (CMS) and investigate the impact of these strategies on novice CAD users.

1.3 Background of the research

Developing a tool to teach effective use of CAD is not a new concept and it was important to ensure that the work was original. Several resources claim to teach effective use of CAD by teaching the user how to use the features [Toogood 2006a, Alias StudioTools 2003, McMahon & Browne 1998]. A problem with some of the resources [Toogood 2006a, 2006b, Alias StudioTools 2003] is that they are software specific, so although the user has a general understanding of how one CAD package works, this may be entirely different to another.

Previous research has suggested that there exist higher-level modelling strategies, whereby users’ syntactic and semantic knowledge transfers between 3D CAD packages [Wiebe, 2000:435]. Hamade et al. [2007] provide interesting information relating to how students learn to use CAD with regard to specific, observable tasks as the students learn to ‘master’ the CAD package. The doctorate research described in this thesis therefore moves forward from this standpoint and a resource has been produced to communicate 3D CAD to novice CAD users, whether in an academic or industrial context, continuing and furthering the higher-modelling strategy notion [Wiebe, Ibid]. The doctorate research investigates the concept of ‘feature-based’, ‘overarching’ and ‘detailed’ approaches for use of 3D CAD, termed generally as CMS.
As CAD packages evolve, there will be an even greater need to be able to use them effectively, interchanging CAD skills between new versions of software and entirely different CAD packages. This is especially important in the progression between higher education and industry, as there is a high chance that a different 3D CAD package will be used in industry than in education [Wiebe 2003:15]. If developing CMS for product designers produces a more competent CAD user, this tool could become a key instrument within the design industry and education alike, as the general principles are not software specific.

1.4 Scope of the research

Modelling a design can take the form of a 2D or 3D representation and communicating the design can be achieved in many different ways, depending on the type of product or system being designed and the audience to which it is being presented. A model in design, as Rodriguez [1992] states ‘...is an accurate representation of an actual device, system, or process’ [Ibid:177]. Various types of CAD models exist, including wireframe, surface and solid representations [McMahon & Browne 1998:50]. These, as McMahon & Browne [Ibid] suggest, can be broadly described as below:

- A wireframe model uses a collection of curves to represent the 3D form [Ibid]
- A surface model uses a collection of surfaces, often attached to a wireframe [Ibid]
- A solid model uses geometric primitives or faces, edges and vertices, defining the boundary of the part [Ibid]

Surfaces define geometry of shape and form in space, but have no thickness and hence no mass. Solid features can be defined as real objects, distributing mass, material and other properties. Many CAD systems are able to combine surface and solid modelling, typically adding thickness to surfaces creating complex solid features. This integrates the modelling tools in a single system, characterised by systems like Pro/ENGINEER.

Examples of each of these representations are shown in Figure 4.
A key difference between surface and solid modellers is the method with which the CAD package represents and processes the 3D geometric form. There are two distinct ways that a CAD package processes solid models, as noted by McMahon & Browne [Ibid:43-46]:

a) Through the use of solid primitives (cuboids, cylinders, spheres, cones) and Boolean operations (termed as ‘constructive solid geometry’) [Ibid]
b) Through the definition of connectivity between surfaces and the identification of a solid side to each surface, particularly using NURBS (termed as ‘boundary representation’) [Ibid]

The surfaces can be defined in three ways within a CAD system, as described by McMahon & Browne [Ibid:37-38]:

a) Through the use of control points (e.g. Bezier surfaces, Quadratic B-spline surface) [Ibid]
b) Through the use of defined curves (e.g. tabulated cylinder, ruled surface, surface of revolution, swept surface, sculptured or curve-mesh surface) [Ibid]
c) Through the use of chamfer surfaces or fillet surfaces [Ibid]
There are a plethora of CAD packages that are available to product designers, including primarily solid modellers, such as AutoCAD, SolidWorks, Solid Edge, Mechanical Desktop or primarily surface modellers, such as Catia, 3D StudioMax, Alias or Rhino. There are also, therefore, many approaches to designing with CAD, including 3D scanning, haptic modelling [Campbell et al. 2003] and importing and transforming 2D freehand sketches into 3D designs [Qin et al. 2000, 2001]. It should be noted, however, that the focus of this research is on modelling strategies within the CAD software tools, either as a means of improving designing within the software itself or to better complement other design activities undertaken outside the software.

PTC, the produces of Pro/ENGINEER and Pro/DESKTOP, claim to be the largest software company in the world [www.ptc.com:2009] and are a major stakeholder in CAD education in relation to schools and higher education in the UK [www.cadinschools.org 2009]. In 1999, PTC donated Pro/DESKTOP software to 6,000 schools in the UK as part of ‘The Schools’ CAD/CAM Initiative’ [DATA]. As a result, the majority of CAD users in schools are taught to use the 3D solid modelling package Pro/DESKTOP [www.cadinschools.org 2006] and move onto the more complex Pro/ENGINEER when they have more experience. Therefore, Pro/ENGINEER and Pro/DESKTOP have been used significantly during this research. This provided access to a large number of participants who were:

- Learning to use Pro/DESKTOP
- Learning to use Pro/ENGINEER
- Transferring from Pro/DESKTOP to Pro/ENGINEER
- Experienced in using Pro/DESKTOP
- Experienced in using Pro/ENGINEER

It should be noted, therefore, that the focus of this research is on solid, constraint-based modelling, although it is envisaged that many of the principles described herein are generic to both solid and surface modellers.
1.5 Research aims addressed in the ‘Exploratory Study’

The initial research aims addressed in the ‘Exploratory Study’ [Chapter Two] can be seen in Table 3.

<table>
<thead>
<tr>
<th>Initial research aims: ‘Exploratory Study’ [refer to Chapter Two]</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To explore and define the notion of CMS</td>
</tr>
<tr>
<td>• To further define the research area</td>
</tr>
</tbody>
</table>

Table 3: Initial research aims addressed in the Exploratory Study

1.6 Structure of the research programme

The research followed a number of phases, although the structure of the research was not as clear cut and involved a continual process of planning, acting, observing/evaluating and reflecting [Wellington, J., 2000:22]. Gray & Malins [2004:82] describe a generic structure for the research process, which has been adapted to show the structure of this research programme, in Figure 5. An ‘Exploratory Study’ was undertaken to learn how CAD is used within a design and industrial environment and how ‘practiced’ CAD users model products. This led to a pilot study, involving novice CAD users. From this, it was evident that there were a number of issues affecting the way people use CAD, which provided a basis for some material to be piloted a number of times within the ‘Pilot Study Two’ phase. The material was then worked into a useable tool, which was applied within the Main Study. The outcome from the Main Study points at issues which are imperative in educating novice CAD users and has a significant impact on how CAD is taught both in educational institutions and industry.
1.7 Structure of the thesis

The structure of the thesis is described diagrammatically within the Abstract. Additionally, it was felt to be important, at this point, to clarify three aspects relating to the structure of the thesis:

1. From this chapter onwards, summaries have been used at appropriate points throughout the thesis, which focus on key points made previously [refer to Table 4].
2. Initial research aims have been presented in a table with a white heading and focused research aims have been presented in a table with a red heading [refer to Table 5].
3. Specific research objectives necessary to fulfil the aim in each chapter have been added with a black heading [refer to Table 6].

<table>
<thead>
<tr>
<th>Summary</th>
<th>Outlines the key points from each section</th>
</tr>
</thead>
</table>

Table 4: Summaries

<table>
<thead>
<tr>
<th>Initial research aims</th>
<th>Indicates the research aims relevant at the starting point of the research programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focused research aims</td>
<td>Indicates the research aims that have evolved as a result of the research</td>
</tr>
</tbody>
</table>

Table 5: Key for research aims tables

| Specific research objectives | Indicates research objectives that are specific to a particular chapter/study |

Table 6: Key for research objectives tables

The research aims, objectives and questions for the research can be seen in Table 7.
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Research aims</th>
<th>Specific research objectives/questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>N/A - Introduction</td>
<td>To explore and define the notion of CMS through the use of CAD model examples and a review of literature To develop CMS through a review of literature and existing CAD learning resources To confirm the emergent theories from the literature through dialogues with ‘practiced’ and ‘novice’ CAD users</td>
</tr>
<tr>
<td>Two</td>
<td>To explore and define the notion of CMS To further define the research area</td>
<td>To explore and define the notion of CMS through the use of CAD model examples and a review of literature To develop CMS through a review of literature and existing CAD learning resources To confirm the emergent theories from the literature through dialogues with ‘practiced’ and ‘novice’ CAD users</td>
</tr>
<tr>
<td>Three</td>
<td>To identify appropriate methods for undertaking the research</td>
<td>To explore and review research methods through a review of literature</td>
</tr>
<tr>
<td>Four</td>
<td>To generate an accurate description of what should be included in the CMSS material and consider the methods with which to communicate this information effectively to novice CAD users</td>
<td>To discover whether novice CAD users adopt different strategies to model the same part To establish what factors affect the strategy that is chosen to model a part</td>
</tr>
<tr>
<td>Five</td>
<td>To define specific content that should be included in the CMSS material To define the prerequisite knowledge that the learner would need in order to implement the CMSS material</td>
<td>To define specific content that should be included in the CMSS material To define the prerequisite knowledge that the learner would need in order to implement the CMSS material</td>
</tr>
<tr>
<td>Six</td>
<td>To consider the key approaches to teaching CAD To examine the principles of blended learning with a view to providing an engaging medium for all learners To describe the process that incorporates this information into the CMSS material</td>
<td>To consider the key approaches to teaching CAD To examine the principles of blended learning with a view to providing an engaging medium for all learners To describe the process that incorporates this information into the CMSS material</td>
</tr>
<tr>
<td>Seven</td>
<td>To generate feedback about the CMSS material from a range of CAD users</td>
<td>To generate feedback about the CMSS material from a range of CAD users</td>
</tr>
<tr>
<td>Eight</td>
<td>To develop a final version of the CMSS material, for use within the main PhD trial</td>
<td>To develop a final version of the CMSS material, for use within the main PhD trial</td>
</tr>
<tr>
<td>Nine</td>
<td>To establish whether the CMSS material produces a more efficient CAD user</td>
<td>Did the CMS Group use any of the strategies described in the CMSS material to create their model? Did the CMS Group use a more effective strategy than the Control Group? Could members of the CMS Group make design changes in less time than members of the Control Group? Did the CMS Group feel that the material had helped them? What was good about the material? What could be improved?</td>
</tr>
<tr>
<td>Ten</td>
<td>N/A – Discussion</td>
<td></td>
</tr>
<tr>
<td>Eleven</td>
<td>N/A – Conclusions</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Research aims, objectives and questions
2 EXPLORATORY STUDY

Overview: The notion of CMS is explored within this chapter and prior art is reviewed leading to the generation of themes relating to strategic use of CAD. ‘Practiced’ CAD users are consulted to further explore the emergent themes from the literature, leading to a definition of the research area and the compilation of focused research aims.

2.1 Introduction

Due to the advances in computer technology over the years, designers are increasingly using CAD as a tool throughout the process of design [refer to Chapter One, section 1.1 - ‘The generic Product Development Process’ Ulrich & Eppinger Op. Cit.]. Therefore, there exists a real need for product designers to be able to model and manipulate forms easily using CAD. However, it appeared that a resource that aimed to communicate CAD on a strategic level did not exist [refer to Chapter One, section 1.1]. Having established the overall aim of the research [refer to Chapter One, section 1.2], it was therefore necessary to undertake an ‘Exploratory Study’ in order to ensure that the research was to make an original contribution to knowledge.

General research aims were established at the beginning of the research agenda [refer to Chapter One, section 1.5 and Table 7 and Table 8], which have been explored within this chapter in order to further define the direction of the research. It should be noted that a 20,000 word literature review was undertaken on the subject of cognitive psychology, which was useful as background information as it provided a valuable insight into how people learn, build mental models, comprehend language and visualise 3D forms. As cognitive psychology was found to be an extremely broad subject, a particular focus was made on visualisation and Experiential Learning Theory [Kolb 1984, Kolb et al. 2000], which are documented in Chapter Six. The literature review,

3 ‘Practiced’ CAD users have been defined (throughout the thesis) as those who have used CAD in a design context for at least three years.
along with the information detailed in this chapter, was documented in the End of Year Report and presented during a validation meeting [McNiff et al. 2003] at the end of the first phase of the research [refer to Figure 5 in Chapter One, section 1.6].

### Initial research aims: ‘Exploratory Study’ [from Chapter One]

- To explore and define the notion of CMS
- To further define the research area

<table>
<thead>
<tr>
<th>Table 8: Initial research aims [refer to Chapter One, section 1.5]</th>
</tr>
</thead>
</table>

In order to explore these aims, it was necessary to undertake a review of literature and prior art, as well as collecting primary evidence from CAD users. This chapter has been split into the three research objectives listed in Table 9.

### Specific research objectives: ‘Exploratory Study’

- To explore and define the notion of CMS through the use of CAD model examples and a review of literature
- To develop CMS through a review of literature and existing CAD learning resources
- To confirm the emergent theories from the literature through dialogues with ‘practiced’ and ‘novice’ CAD users

<table>
<thead>
<tr>
<th>Table 9: Initial research objectives - Exploratory Study</th>
</tr>
</thead>
</table>

#### 2.2 CAD Modelling Strategies

The first part of the research involved fully defining the notion of CMS, which can also be termed as ‘CAD technique’, ‘CAD approach’ or ‘strategic use of CAD’. The term ‘CAD modelling strategies’ (or ‘CMS’) covers any approach that is used to model on
CAD. For example, the tyre shown in Figure 6 can be modelled using three different strategies [refer to Table 10].

![Figure 6: Generic tyre rendering and line drawing](image)

| Strategy A: | i) Create the main body of the tyre using a circular protrusion  
|            | ii) Create the lip on the tyre by cutting into the extrusion  
|            | iii) Create the tyre tread using an extrusion (using either a protrusion or a cut)  
|            | iv) Pattern the tyre tread  |
| Strategy B: | i) Create the tyre by sketching the top profile of the tyre, which includes each of the individual tyre treads  
|            | ii) Extrude the profile  
|            | iii) Create the lip on the tyre by cutting into the extrusion  |
| Strategy C: | i) Create the tyre by sketching the cross section of the tyre to form a profile  
|            | ii) Revolve the cross sectional profile  
|            | iii) Create the tyre tread using an extrusion (using either a protrusion or a cut)  
|            | iv) Pattern the tyre tread  |

Table 10: Potential strategies for modelling the tyre on Pro/ENGINEER
It is clear that the same physical model can be generated using any of the three strategies noted above\(^4\), although the strategy that is selected has vast implications on the time it takes to model the part and the ease with which the user can change key aspects of it (e.g. the number of tyre treads, the diameter of the tyre or the width of the tyre). To a novice CAD user, it might appear that Strategy B is the most effective strategy as it involves the least amount of steps. However, on looking further into the consequences of creating the tyre shown in Figure 6 using Strategy B, it was clear that this would take the most amount of time to create and be the most difficult to make key design changes to at a later point in the process.

It would appear, therefore, that there exist both effective strategies and ineffective strategies, where effective strategies allow the designer to capture their design intent and make changes to their CAD model easily. Bhavnani & John [1997] provide a useful definition of efficient strategic use of CAD, where they note that ‘The knowledge of these alternate ways [of modelling on CAD] and how to choose between them can be referred to as strategic knowledge’ [Ibid:94]. For the purpose of this thesis, a definition of ‘effective’ CMS (using ‘strategic knowledge’ [Ibid:94]) has been termed as:

*Using the most effective features to create an accurate CAD model of a design/concept, allowing key design changes to be implemented quickly and efficiently.*

Therefore, the next stage was to review the prior art to establish whether any existing CAD learning resources or literature attempted to communicate effective strategic use of CAD.

\(^4\) It should be noted that the three strategies above are not an exhaustive list, as combinations of each strategy can produce different ‘strategies’.
Summary: CAD Modelling Strategies

- For many products, there exist several strategies that can be implemented to produce the same physical 3D CAD model.
- A novice CAD user may not have the knowledge (typically gained through experience) to differentiate between an effective and non-effective strategy.
- As the strategy that is selected has vast implications on the time it takes to model the part and the ease with which it is possible to change key aspects of it, it is imperative that product designers can select an appropriate CMS.

2.3 Prior art: CAD learning resources

An exploratory review of literature and CAD learning resources\(^5\) was undertaken in order to understand whether the notion of effective CMS had been identified in previous work. Initially, it appeared that effective strategic use of CAD was a skill that was implemented by ‘practiced’ CAD users, but not taught in CAD resources aimed at novice CAD users [refer to Chapter One, section 1.1]. The problem seemed to be that novice CAD users were taught to use all of the basic features (and could produce an accurate representation of a part/product), but were not necessarily shown how to use an effective strategy that would allow them to redesign their model with ease. Therefore, it was necessary to review the prior art in the field to ensure that the research would make an effective contribution to knowledge.

The information collated during the ‘Exploratory Study’ has been split into a number of themes, according to the literature and the researcher’s prior CAD experience, which are explored in more detail throughout this chapter.

- ‘Feature-based’ approach
- ‘Overarching’ approach
- ‘Detailed’ approach

\(^5\) It should be noted that resources that aim to introduce novice/new users to CAD have been focused on within the research.
2.3.1 ‘Feature-based’ approach

A plethora of CAD resources provide the user with information and examples relating specifically to using the basic CAD features [refer to Table 11]. These resources form the first theme, termed the ‘feature-based’ approach. This approach to teaching CAD is used by all major CAD software providers (in particular Pro/ENGINEER and Pro/DESKTOP) and acts as a guide to using the software. It is clear that within teaching materials using a ‘feature-based’ approach, experience of the CAD system underpins the learning experience.

<table>
<thead>
<tr>
<th>Basic CAD features:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blend</td>
</tr>
<tr>
<td>Chamfer</td>
</tr>
<tr>
<td>Draft</td>
</tr>
<tr>
<td>Extrusion (which includes protrusions and cuts)</td>
</tr>
<tr>
<td>Insert hole</td>
</tr>
<tr>
<td>Mirror</td>
</tr>
<tr>
<td>Pattern</td>
</tr>
<tr>
<td>Project</td>
</tr>
<tr>
<td>Revolve</td>
</tr>
<tr>
<td>Round</td>
</tr>
<tr>
<td>Shell</td>
</tr>
<tr>
<td>Sweep</td>
</tr>
</tbody>
</table>

Table 11: Examples of basic CAD features

Many resources cover an in depth examination of the key features [Pro/ENGINEER COAch 2002, McMahon & Browne 1998, Rodriguez 1992] and often progress sequentially through the application of the features to a specific part model, typically using a mechanical part as an example. Koser & Zirwas [2009] use a ‘layered approach’ to presenting the information to the learner, starting with the basics of AutoCAD and building the level of difficulty up gradually. These resources can be split into software specific learning resources, whereby the information is generally specific to a particular manufacturer [e.g. Pro/ENGINEER COAch 2002, Toogood 2006a, 2006b] and non-software specific, generic resources [e.g. McMahon & Browne 1998, Rodriguez 1992].

A non-software specific representation of the use of basic CAD features has been provided by Rodriguez [Ibid], who considers the ‘generic primitives’ of a form in order to establish the modelling strategy, as can be seen in Figure 7. This provides the user with a visual representation of each of the features.
McMahon & Browne [1998] also discuss non-software specific ‘techniques for geometric modelling’, primarily from an engineering, mathematical perspective. He notes that a number of different methods can be used to generate a model, the most important of which, he claims is the ‘sweep’ feature, involving sweeping a two-dimensional profile along a specific trajectory [Ibid:82-83]. Although these resources provide a useful reference to using CAD, they do not approach strategic use of CAD in any detail and instead focus on the functionality of the features.

It was interesting to discover that along with the basic features noted in Table 11, it was also seen to be important to show the user how to recover from an error message on a CAD system [Toogood & Zecher 2006:i]. This was encouraging, as typical error message feedback can often seem daunting to a novice CAD user [refer to Figure 8] and prompt them to restart the model from the beginning, rather than resolve the error.
Summary: ‘Feature-based’ approach

- The ‘feature-based’ approach underpins all CAD-based training and although teaching resources that fall into this category can be thought of as crucial to learning the functionality of the features, they do not approach strategic use of CAD in any detail.

2.3.2 ‘Overarching’ approach

In order to make a distinction between those resources that simply show the user how to use the basic CAD features and those that consider the ‘bigger picture’, another category was identified, termed as the ‘overarching’ approach. The ‘overarching’ approach differs from the ‘feature-based’ approach, as it is more strategic in nature and
considers how to model the product as a whole. This might include using symmetry on both a part level and assembly level to ensure that both sides of the model are exactly the same (rather than create each half independently), or using a horizontal/top-down approach whereby the user is encouraged to reference all items to datum planes instead of other features (to ensure that they can make modifications to their products easily). Other ‘overarching’ approaches identified included the ‘duplicate part’ strategy, the ‘skeleton’ strategy and the ‘vertical’ strategy.

**The ‘duplicate part’ strategy**
A useful feature of Pro/ENGINEER and Pro/DESKTOP is the ability to duplicate parts, either dependently or independently [Toogood 2006a]. The ‘duplicate part’ strategy therefore shows CAD users how to create a duplicate part, either as a direct copy or as a mirror. This approach exploits the parametric nature of the CAD software. Using the ‘duplicate part’ strategy, CAD users can save time when modelling and can make design changes quickly and effectively.

**The ‘horizontal’ strategy**
Horizontal Modelling, a patented design methodology by Delphi Technologies, Inc. [Solash 2007], is an approach to modelling that recommends that all items are referenced to datum planes, as opposed to other features. The Horizontal Modelling approach differs from ‘traditional’ parametric modelling as it does not make use of parent/child relationships, thus ‘...erasing the disadvantages caused by feature dependencies in product and manufacturing process design’ [Ibid:3] [refer to Figure 9]. It is claimed that creativity and innovation may be enhanced through the use of an easily changeable CAD model [Solash 2007].
Figure 9: Vertical versus Horizontal Modelling approaches [Teague 2003:1]

Solash [2007] claims that the use of parent/child relationships are ineffective when making small changes to the design, as the user would often have to dismantle their model [Ibid:3]. Solash [Ibid] claims that through the use of Horizontal Modelling, designers are able to rapidly make changes to any of the features. The basis of this modelling approach is that all features are created from base datum planes and offset datum planes, ensuring that there are no dependencies on the existing model [Ibid]. Solash [Ibid] states that:

Use of HM allows engineers to capture design intent without creating parent/child relationships, erasing the disadvantages caused by feature dependencies in product and manufacturing process design. Solash 2007:3

However, a major weakness of this approach is that parts cannot rely on geometry from other features, which is especially useful when sharing geometry between features and parts. Sharing geometry between features and parts is a major benefit of modern parametric modelling and it is therefore believed that ignoring this functionality would be taking a step ‘backwards’. Although it might be useful to reference geometry such as datum planes in some situations, the Horizontal Modelling approach was not used (in its entirety) within this research.

Additionally, it should be noted that parametric modelling is often the subject of much debate, regarding the notion that designers are forced to be too precise with their
geometry, too early on in the design process [Hill 1994]. However, it is believed that when used effectively, designers should easily be able to change key geometry within their models.

**The ‘skeleton’ strategy**

The ‘skeleton’ CMS is a very powerful parametrically driven ‘overarching’ approach and is taught on the Advanced CAD module at Loughborough University. This involves the creation of a ‘skeleton’ model containing all of the key geometry (especially aspects that are likely to be modified) and referencing all other parts created to this ‘skeleton’. Figures 10 and 11 show a computer mouse created using the ‘skeleton’ strategy in Pro/ENGINEER Wildfire, alongside the ‘skeleton’ model that it was referenced to, containing the key geometry.

![Figure 10: Rendered model of a computer mouse](image1)

![Figure 11: ‘Skeleton’ model of a computer mouse](image2)
As can be seen, key geometry such as the cutting line and button profiles as well as the surfaces used to create the shape of the mouse are contained within one model. If, for example, in industry, the client required the shape of the mouse to be modified, the product designer could simply alter the ‘skeleton’ model and all of the other parts would update automatically (due to the parametric nature of the software). If all of the parts had been created separately and the same request received from the client, the product designer would have to modify each part individually, ensuring that they all follow the same curvature and fit together accurately. This model could take a considerable amount of time to modify.

The ‘skeleton’ strategy taught by Loughborough University is also described by Brown et al [2001] as the ‘systematic approach’ which involves creating a ‘skeleton’ of the desired product using curves and subsequently creating surfaces from the curves.

**The ‘symmetry’ strategy**
The ‘symmetry’ strategy is another useful CMS that involves mirroring on a sketch level (i.e. mirroring sketch geometry) or on a part level (i.e. mirroring a number of features), as shown in Table 12. The ‘symmetry’ strategy is taught within basic CAD lectures at Loughborough University and is an extremely useful strategy for generating certain types of CAD models [Bhavnani & John 1997]. Again CAD users can save time when modelling when using this approach and can make design changes quickly and effectively.
Symmetry within the ‘overarching’ approach | Symmetry within the ‘detailed’ approach
---|---
Car body example | Desk lamp example

Table 12: Examples of the application of the ‘symmetry’ strategy

**The ‘vertical’ strategy**

‘Vertically feature-based design’, ‘vertical modelling’ or ‘feature-based modelling’ are terms used to describe the creation of parts or products on CAD through the use of parent/child relationships, where parts are linked and referenced parametrically to other parts or features. This approach utilises the parametric nature of modern CAD software (such as Pro/ENGINEER and Pro/DESKTOP) and, again, is taught within basic CAD lectures at Loughborough University.

However, there are some problems associated with the use of this method. Solash [2007] claims that vertical modelling is an imperfect approach due to ‘inherent limitations’ [Ibid:3], for example, it is often a very difficult and complicated process to make changes to features, resulting in designers needing to ‘dismantle’ the model or recreate it completely [Ibid]. Teague [2003:1] claims that difficulties arise when the user attempts to modify the CAD model, as features are built up on top of each other in a vertical format, creating dependencies on one or more existing features. For example, if a designer needed to delete the second feature that was created, then all proceeding
features would be deleted due to the parent/child relationship within the model. However, when used effectively, this approach is very useful for CAD users, allowing them to reference key geometry such as cutting lines or curves and was therefore considered within this research.

**Summary: ‘Overarching’ approach**

- The ‘overarching’ approach provides the user with strategic advice on how to model the product as a *whole*. This approach is key to modelling on CAD, although it was clear a resource that communicates the range of ‘overarching’ approaches available to the user did not exist.

### 2.3.3 ‘Detailed’ approach

The third category was identified as a result of aspects that were missing from existing CAD resources, and was termed the ‘detailed’ approach. This provides specific details on *how* to model effectively on CAD and differs from the ‘feature-based’ approach as it does not claim to be a reference for the features on the CAD package, but a more generic top-line approach, involving the consideration of *how* and *where* a feature should be used. Bhavnani et al. [1999] provides useful documentation relating to teaching learners to use architectural computer-aided drafting systems strategically. Although their focus is on 2D sketching, rather than 3D CAD modelling, they note the importance of using the pattern and mirror features, which would form part of the ‘detailed’ approach. It was found that there were several aspects that appeared to be missing from existing CAD resources, as detailed below.

- How to share profile geometry between features and parts, termed the ‘profile-profile’ strategy
- How to share reference geometry between features and parts, termed the ‘reference-reference’ strategy
- When a revolve should not be used (e.g. in the creation of a cylinder, where a simple extrude might be more effective), termed the ‘revolve’ strategy
• Where a sweep/blend should not be used (e.g. in the creation of a cylinder, where a simple extrude might be more effective), termed the ‘sweep’ strategy
• How to apply symmetry within sketcher [Bhavnani et al. 1999], termed the ‘symmetry’ strategy [refer to section 2.3.2]

It is believed that through actively encouraging the user to consider alternate approaches to modelling on CAD, that they will be able to select the most appropriate features and therefore create an effective CAD model that they can easily make design changes to.

<table>
<thead>
<tr>
<th>Summary: ‘Detailed’ approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The ‘detailed’ approach actively encourages the CAD user to consider alternate approaches to modelling on a feature level and to understand the context in which specific features should be used.</td>
</tr>
</tbody>
</table>

2.4 CAD user research
In order to confirm the emergent themes from the literature and existing CAD education, research was carried out using CAD users of differing abilities. Primarily, ‘novice’ CAD users were consulted regarding their use of Pro/DESKTOP at A-Level and the subsequent ‘transfer’ of knowledge to the more complex Pro/ENGINEER. ‘Practiced’ CAD users were then considered to confirm the emergent themes from the literature.

2.4.1 Transfer of knowledge
As mentioned in Chapter One, previous research has suggested that there exist higher-level modelling strategies, whereby users’ syntactic and semantic knowledge transfers between 3D CAD packages [Wiebe, 2000:435]. Although the research detailed in this thesis aims to move forward from this standpoint by communicating specific content to novice CAD users, it was still necessary to consider what knowledge transfers between CAD packages, especially as there is a high chance that a different 3D CAD package will be used in industry than in education [Wiebe, 2003:15].
In order to test the ‘higher level modelling strategies’ [Ibid] theory, Wiebe [2003] asked participants to model a valve on Pro/ENGINEER (which they had used before) and then again on SolidWorks (which was new to the participants). Wiebe [Ibid] found that ‘...students were able to transfer knowledge which they learned from working on Pro/E for most of a semester and use it to create a model in SolidWorks’ [Ibid:24]. Wiebe [Ibid] concluded that there was more educational worth when exercises that ‘...reward higher level thinking rather than encyclopedic knowledge of a specific software tool’ [Ibid:27] are used.

It is encouraging to see that rote memorization of features and tools appear to have less educational worth than those that ‘reward higher level thinking’ [Ibid:27], perhaps where the learner actively considers and makes decisions related to their CAD model. Wiebe [Ibid] suggested that the ‘transfer’ of knowledge (and potentially CMS knowledge) would happen when the learners had mastered the basics of the package, although it was unclear what the ‘basics’ of mastering the CAD package were and what exactly transferred between CAD packages.

The specific research objectives for this part of the research can be seen in Table 13.

<table>
<thead>
<tr>
<th>Specific research objective - Transfer of knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To establish how the Pro/DESKTOP software had been used within the participants’ A-Level Design and Technology course</td>
</tr>
<tr>
<td>• To identify the impact of that use on how effectively participants developed CAD modelling capability with the more complex Pro/ENGINEER software</td>
</tr>
</tbody>
</table>

Table 13: Specific research objective - Transfer of knowledge

Research was therefore undertaken involving participants who had used Pro/DESKTOP at A-Level and were subsequently learning to use Pro/ENGINEER.
A purposive convenience sampling strategy was used to target questionnaires at Year One students on Industrial Design and Technology at Loughborough University. The questionnaire helped to identify those participants who had made significant use of the software and those who had not applied it in a design context. This generated quantitative data regarding their depth of Pro/DESKTOP use at A-Level. 36 respondents (30% of the year) had used Pro/DESKTOP during their A-Levels. Of these 36 respondents, 27 had used Pro/DESKTOP ‘significantly’.

Having established which respondents had used Pro/DESKTOP significantly, it was necessary to undertake a comparison of marks for an assignment that was given to the entire year, to establish whether use of Pro/DESKTOP at A-Level had had an effect on the participant’s achievement at Undergraduate level. The comparison was made between participants who had used Pro/DESKTOP to model their major project at A-Level and those who had not. The assignment was uniform across the whole year and the mark itself took account of the features used on Pro/ENGINEER and how well the product had been modelled. The mean marks for this Pro/ENGINEER assignment differed significantly ($t_{(118)}=-3.83$, $p<.01$) depending on whether the participant had used Pro/DESKTOP at A-Level or whether they had not. The participants who had used Pro/DESKTOP to model their A-Level major project achieved a mean mark of 70.7% whereas the mean mark for the participants who had not used Pro/DESKTOP for their A-Level major project was 58.7%. This suggested a 12.0% difference in respect of the mean of the marks between groups and suggested that there was a transfer of knowledge/skills between CAD systems.

However, looking further into the data, it was found that there was no advantage in simply showing A-Level students how to use Pro/DESKTOP. In fact, the data suggested that this resulted in a disadvantage compared with those who had applied Pro/DESKTOP to their A-Level project and even compared with those who had never used Pro/DESKTOP before, as can be seen in Table 14.

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6 ‘Significantly’ implies that the participant had applied Pro/DESKTOP in a design context (e.g. to develop their design), as opposed to simply following a tutorial.
Significant Pro/DESKTOP users (Pro/DESKTOP has been applied to the participant’s design work):

Non-significant Pro/DESKTOP users (Pro/DESKTOP has not been applied to the participant’s design work):

Non-Pro/DESKTOP users:

Average mark for group (%): 70.6  54.3  59.2

Table 14: Comparison of prior Pro/DESKTOP use and marks achieved in the first Pro/ENGINEER assignment

Summary: Transfer of knowledge

- Having investigated Wiebe’s [2000, 2003] ‘higher-level modelling strategies’ concept further, it was found that there did appear to be a ‘transfer of knowledge’ between CAD packages, but it was found to be important for the user to make significant use of the primary CAD package in the first instance. The findings were presented (and published) at the International DATA conference, which raised an interesting discussion relating to the transfer of knowledge. In particular, it was encouraging to find that if CAD users were taught how to use effective CMS (i.e. make significant use of the CAD package within a design context), that these skills could potentially transfer to other CAD packages, which conformed with Wiebe’s [2000, 2003] ‘higher level modelling strategies’ concept.

2.4.2 ‘Practiced’ CAD users

‘Practiced’ CAD users were consulted to confirm the emergent theories from the literature and to confirm the definition of ‘effective’ CMS. This was achieved by:

a) Analysing the CAD models from ‘practiced’ CAD user participants in their final year of Industrial Design and Technology at Loughborough University

b) Collecting primary evidence from ‘practiced’ CAD user participants through the use of a questionnaire
c) Conducting a group discussion involving ‘practiced’ CAD users as well as academics with a background in CAD

Participants were classified as ‘practiced’ CAD users if they had used CAD for at least three years. The participants had varying backgrounds and many of them had spent at least one year using CAD within a design context in industry. The sample size for this study was relatively small, as the researcher was aiming to confirm the emergent issues from the literature using a Grounded Theory approach [refer to Chapter Three, section 3.1.2].

CAD model analysis

Primarily, it was important to discover whether the ‘practiced’ CAD users had made use of a ‘detailed’ or ‘overarching’ approach through a thorough analysis of the participants’ CAD models [a sample analysis can be found in Appendix 5] submitted for a coursework assignment on the Advanced CAD module at Loughborough University. The specific research objective for this part of the research can be seen in Table 15.

<table>
<thead>
<tr>
<th>Specific research objective: CAD model analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>To confirm the emergent themes from the literature through an analysis of ‘practiced’ CAD users’ models</td>
</tr>
</tbody>
</table>

Table 15: Specific research objective - CAD model analysis

Again, a theoretical purposive sampling strategy was used to select the participants, as it was necessary to select participants who had chosen to model comparable products. This allowed the researcher to compare strategies used to model similar products. The participants’ CAD experience can be seen in Table 16.
<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Number of years using CAD</th>
<th>Number of years in industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>P207</td>
<td>3</td>
<td>1</td>
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<tr>
<td>P208</td>
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<td>P212</td>
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</tr>
<tr>
<td>P215</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 16: Participants’ CAD experience - CAD model analysis

Having analysed the CAD models, it was confirmed that the way in which the participant approached the modelling of the products using CAD affected the time it took to model the part, the ease with which a part could be modified and the amount of features that were used. The information generated from this study was presented visually, as can be seen in Figures 12 to 15.

The first presentation board provided five examples of models that had been analysed [refer to Figure 12]. The assignment allowed the participants to model any product on Pro/ENGINEER, so the products selected by the researcher were chosen because they provided more than one strategy for modelling the same product. The main aim of this was to provide information on:

- The number of parts that were created
- The number of sub-assemblies that were created
- The general approach
- A breakdown of how a selected part was constructed
Having analysed the models, it was clear that the strategy that was used affected the number of features that were employed and the ease with which the model could be modified. For example, one version of the top shell of the mouse had been modelled in halves and mirrored [refer to ‘symmetry’ strategy, section 2.3.2], the second had been modelled by creating each part separately and the third used a shared geometry approach [refer to ‘skeleton’ strategy, section 2.3.2]. By creating each part separately, a lot of work would have to be undertaken in order to modify the shape of the mouse to ensure that all of the parts would fit together accurately. Through the use of a ‘skeleton’ strategy, however, design changes could be easily reflected throughout all parts, exploiting the parametric nature of the CAD software (Pro/ENGINEER).

Figure 13 uses the example of a drill and highlights a specific part, which could have been created using a different, more effective, strategy. A timed test was undertaken by
the researcher to discover how much time could have been saved using an alternate approach. It was found that the mean time (out of three attempts) that it took to model the part using the strategy that the participant had used was 2 minutes and 31 seconds, whereas the mean time taken to model the part using the alternate approach (again, out of three attempts) was 1 minute and 22 seconds. This resulted in a time difference of over one minute on this particular part. In general terms, if this was applied to a model consisting of 30 similar parts, over half an hour could have been saved during the modelling process. Additionally, if design changes were required to this part, it would take the designer longer to make the changes using the participant’s strategy. This shows that it is necessary to use an effective CAD modelling strategy regardless of the number of parts that are being generated.
Figure 14 shows an example CAD model of a toy car and details the difference in time with regard to the *redesign* aspect of the modelling process. To illustrate the example, a
cog part was selected and again, a time trial was undertaken. The participant had modelled the cog by sketching the top profile, including all of the ‘grooves’, as can be seen in Figure 14. However, another strategy that could have been used was to revolve the main body of the cog and create the ‘grooves’ using a patterned cut. The time trial highlighted the difference in time involved in creating the part. The strategy that the participant used took over 10 minutes, whereas generating the part using the alternate strategy took only 4 minutes and 24 seconds on average. Clearly, as well as a consideration of the ‘overarching’ approach that is used to model a part, it is also important to consider how a part is created on a detailed level, which, in this example, involved looking in detail at how a part was sketched (within the ‘sketcher’ mode) before a feature was applied. This shows that although Delphi Technology, Inc. consider the ‘overarching’ approach as the key approach with which to save time and money during the modelling process, it is also important to consider the ‘detailed’ approaches that are being used to model each part. It was also very obvious that it would take a lot longer to modify the cog using the participant’s strategy.
Figure 14: ‘Features’ presentation board 2

Figure 15 provides an example of an ‘overarching’ approach to modelling a product using a ‘skeleton’ strategy [refer to section 2.3.2]. The product (a razor) was created
using datum curves, which have been used to form surfaces. The datum curves have
been shared to create other parts, to ensure that the parts fit together exactly and
provides a good example of the importance of using an effective ‘overarching’ approach
to the generation of other parts.

Figure 15: ‘Shared geometry’ presentation board
It has been shown that a number of the themes highlighted by the review of prior art have been confirmed through the analysis of ‘practiced’ users’ CAD models. In particular, it was found that the strategy that is used to model on CAD can result in a significant difference to the time it takes to model the part and the amount of features that are used. It was found to be important to consider how a part is created on a detailed level, as well as considering the ‘overarching’ approach. Additionally, it was confirmed that the ‘symmetry’ and ‘skeleton’ strategies had been used by the ‘practiced’ CAD users.

‘Practiced’ CAD users’ questionnaire
A questionnaire, aimed at 19 ‘practiced’ CAD users on the ‘Advanced CAD Module’ on Industrial Design and Technology at Loughborough University was generated. This was based on the findings of the previous interviews and CAD model analysis and was used to establish whether the themes detailed above were true across the whole module. The specific research objective for this part of the ‘Exploratory Study’ can be seen in Table 17.

<table>
<thead>
<tr>
<th>Specific research objective: Questionnaire (‘Practiced’ CAD users)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To discover whether the themes generated in the previous interviews were an accurate representation across several ‘practiced’ CAD users on the ‘Advanced CAD’ module at Loughborough University.</td>
</tr>
</tbody>
</table>

Table 17: Specific research objective - Questionnaire (‘Practiced’ CAD users)

A theoretical purposive sampling strategy was used to select the participants for the questionnaires. The questionnaires were distributed to all students on the ‘Advanced CAD’ module on Industrial Design and Technology at Loughborough University. This ensured that access to a large number of ‘practiced’ CAD users was possible. Nineteen participants responded to the questionnaire, as can be seen in Table 18.
The questionnaire can be seen in Appendix 3. The results were analysed on SPSS and descriptive statistics generated. It was clear, from this questionnaire, that the majority of the participants (68%) said that they felt it was an advantage to have thought about the way they were going to model their product before they started modelling on CAD [refer to Figure 16]. This could indicate that careful planning before modelling on CAD could be an important aspect to include in the CMSS material for novice CAD users.

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Number of years using CAD</th>
<th>Number of years in industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>P201</td>
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<td>P228</td>
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</tbody>
</table>

Table 18: Participants’ CAD experience - Questionnaire (‘Practiced’ CAD users)
Figure 16: Whether the participants thought that it was an advantage to have planned the way that they were going to model their product on Pro/ENGINEER before they started modelling

When asked whether a ‘trial and error’ strategy was used to model on CAD, the majority of the participants (89%) said that they had used this approach at some point whilst modelling their product on Pro/ENGINEER. This shows that although they are ‘practiced’ CAD users, there is still an element of ‘trial and error’, perhaps when experimenting with amorphous forms, as can be seen in Figure 17.

Figure 17: Whether the participants used a ‘trial and error’ strategy whilst modelling on CAD
Interestingly, when asked whether the participant would model their product in exactly the same way, 47% noted that they would model it differently. This suggests that they may have experienced problems whilst modelling, which could have been avoided through the use of an alternate approach.

**Group discussion: ‘Practiced’ CAD users**

A group discussion was held with six participants who had used CAD frequently for at least three years. The specific research objective for the group discussion can be seen in Table 19.

<table>
<thead>
<tr>
<th>Specific research objective: Group discussion (‘Practiced’ CAD users)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To help define the notion of CMS and to consider issues related to modelling from a ‘practiced’ CAD users standpoint through a discussion with several ‘practiced’ CAD users.</td>
</tr>
</tbody>
</table>

**Table 19: Specific research objective - Group discussion (‘Practiced’ CAD users)**

A theoretical purposive sampling strategy was used to select the participants for the group discussion, shown in Table 20.

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Number of years using CAD</th>
<th>Number of years in industry</th>
</tr>
</thead>
<tbody>
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<td>P229</td>
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<tr>
<td>P234</td>
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</tr>
</tbody>
</table>

**Table 20: Participants’ CAD experience - Group discussion (‘Practiced’ CAD users)**
The discussion was transcribed, coded and clustered [Miles & Huberman 1984] and the following themes emerged:

**Existing CAD resources**

- It was noted that CADTrain/COAch (a web-based training tool for Pro/ENGINEER) was only effective for a ‘certain’ type of user, who is prepared to ‘put in the hours’ to learn the package [P232]. This was interesting as it suggested that it might be necessary to provide different types of support material, in order to appeal to different learning styles.

- It was suggested that having a tutorial that runs through the entire part using a click-by-click method was not an ideal ‘whole’ solution, as if the user gets stuck on one step, it can put them off completely or make them start again [P230]. It was seen to be beneficial, therefore, to use a range of different tutorials, which focus on different aspects of modelling on CAD and which are not dependant on the previous tutorial to continue with the work.

- Reverse engineering a real-life object was seen to be a good exercise type [P230], as was having a tutorial that can be applied to lots of different products that the CAD user may wish to model [P229].

**CAD modelling strategies**

- Using a ‘trial and error’ strategy, where the user experiments with different forms prior to creating the ‘main’ model was considered to be an acceptable strategy in order to establish which strategies are going to be the most efficient [P234] or even to establish what they were going to be creating on CAD [P232].

- The ‘practiced’ CAD users employed the same ‘overarching’ approach regardless of whether they were creating ‘rough’ models or ‘final’ models [P231]. This suggested that having reached a certain level of competency with CAD, that ‘practiced’ CAD users utilised their CMS knowledge regardless of what ‘grade’ CAD model they were creating.

- The ‘symmetry’ strategy was deemed a useful approach to ensure that the model would update automatically if the first half was altered [P232].

- The ‘skeleton’ strategy was considered to be a useful strategy to learn on Pro/ENGINEER, especially with regard to the potential time savings [P229].
Summary: ‘Practiced’ CAD users

- Having consulted ‘practiced’ CAD users, a number of the key points from the literature were confirmed:
  - The CAD model analysis confirmed that the use of the ‘skeleton’ strategy allowed design changes to be easily reflected throughout all parts, that the use of ‘overarching’ approaches as well as ‘detailed’ approaches are important when designing using CAD and that using the ‘pattern’ strategy could save time when making design changes to the model, both on a detailed level and on an overarching assembly level.
  - The questionnaires showed that prior planning of the CMS was useful and that the ‘trial and error’ strategy was employed by ‘practiced’ CAD users.
  - The group discussion confirmed again that the ‘trial and error’ approach was seen to be a worthy strategy. It also showed that the nature of the ‘overarching’ approach used by ‘practiced’ CAD users remained the same, regardless of the CAD model that was being created (e.g. a ‘rough’ model or a ‘final’ model). It also showed that the ‘symmetry’ strategy, ‘duplicate part’ strategy and ‘skeleton’ strategy were useful (especially when sharing geometry, which has been termed previously as the ‘profile-profile’ strategy and ‘reference-reference’ strategy). It was also interesting to gain feedback on existing CAD resources, to take into account in the design phase of the CMSS material.

2.5 Summary

The ‘Exploratory Study’ was very useful in terms of defining the notion of CMS. It has been shown that a physical model can be created on CAD using more than one strategy and the choice of the strategy that is used can be termed as selecting a ‘CAD modelling strategy’. It was also shown that the selected strategy has vast implications on the time
it takes to model the part and the ease at which the user can change key aspects of it. For the purposes of this research, a definition of effective CMS was generated.

Having reviewed the prior art in the field, three distinct approaches appeared, termed generally as the ‘feature-based’ approach, ‘detailed’ approach and the ‘overarching’ approach.

1. The ‘feature-based’ approach
   The ‘feature-based’ approach provides the user with information and examples relating specifically to using the basic CAD features.

2. The ‘overarching’ approach
   The ‘overarching’ approach provides the user with strategic advice on how to model the product as a whole and includes the following approaches:
   - The ‘duplicate part’ strategy (exploiting the ‘vertical’ strategy)
   - The ‘pattern’ strategy
   - The ‘skeleton’ strategy
   - The ‘symmetry’ strategy

3. The ‘detailed’ approach
   The ‘detailed’ approach provides the user with specific details relating to how to model effectively on CAD, including a consideration of how and where a feature should be used. The ‘detailed’ approach includes the following approaches:
   - The ‘pattern’ strategy
   - The ‘profile-profile’ strategy
   - The ‘reference-reference’ strategy
   - The ‘revolve’ strategy
   - The ‘sweep’ strategy
   - The ‘symmetry’ strategy
Having explored the existing resources and identified a number of key approaches, the next stage was to investigate Wiebe’s [2000, 2003] ‘higher-level modelling strategies’ concept further. Interestingly, it was found that there did appear to be a ‘transfer of knowledge’ between CAD packages, but it was found to be important for the user to make significant use of the primary CAD package in the first instance.

CAD users of differing abilities were then consulted to confirm the emergent themes from the literature. As well as confirming the emergent themes from the literature, it was also found to be useful to:

- Plan the CMS in advance
- Employ the ‘trial and error’ strategy

A definition of a ‘practiced’ CAD user was therefore generated, who is able to use a combination of:

- All the basic features
- An effective ‘overarching’ approach
- An effective ‘detailed’ approach

The next stage was to further define the research area.

### 2.6 Emergent theme: Benefits of using effective CMS for novice users

As a result of an ‘Exploratory Study’, it was found that there were three distinct knowledge areas that the novice CAD user needed to be aware of with regard to the selection of an effective CAD modelling strategy (CMS):

- ‘Feature-based’ approach
- ‘Detailed’ approach
- ‘Overarching’ approach
However, having reviewed the prior art, it was clear that no such resource existed, which combined all three aspects, as denoted by the black circle in Figure 18.

![Figure 18: Knowledge required to select an effective CMS](image)

It was therefore proposed that through the development of CMSS material, which combined all three aspects as shown above, that effective CMS could be communicated to novice CAD users. It was believed that by communicating effective CMS to product designers using a combination of all the basic features, ‘overarching’ approaches and ‘detailed’ approaches, that product designers would be able to capture their design intent effectively, whilst being able to make key design changes to their model, by modelling in an effective and efficient manner.

It was supposed that if such material was developed, that many of the disadvantages noted previously in Table 1 could be negated, as can be seen in Table 21.
Disadvantage of CAD | Potential solution through CMSS material
---|---
Users may not have a thorough understanding of the system [Fischer: 1991:16], which could potentially lead to the user creating the model ineffectively [Bhavnani & John 1997] | Though the use of material that teaches all of the basic features, as well as strategic use of CAD, users should be able to create their CAD models using an effective CMS
Users may find it hard to make design changes to their CAD model if they have not modelled the product effectively | Though the use of material that communicates strategic use of CAD, users should be able to make changes to their product quickly and effectively
CAD could hinder creativity [Lawson 2002] if the user is driven by the CAD package rather than their design ideas (e.g. through a lack of experience) | Having used all of the basic features as well as understanding CMS, users may be able to accurately capture their design intent
For a novice CAD user, modelling on CAD could take longer than sketching during the initial conceptual stage of the design process | The time spent using the CMSS material when working on CAD models during the early stages of the design process would be beneficial during the latter stages, when the CAD model could be exploited for rapid prototyping

Table 21: Negated disadvantages of using CAD

It was envisaged that at the end of the ‘learning process’, the learner would have a number of key learning ‘traits’ as can be seen in Figure 19.

**Figure 19: Traits of the learner**
2.7 Focused research aims

Focused research aims were generated, which related to the emergent theme and arose from the work undertaken previously in the chapter, as can be seen in Table 22.

<table>
<thead>
<tr>
<th>Focused research aims</th>
<th>Where the aim has been addressed in thesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>To identify appropriate methods for undertaking the research</td>
<td>Research methods [refer to Chapter Three]</td>
</tr>
<tr>
<td>To generate an accurate description of what should be included in the CMSS material</td>
<td>Pilot Study One [refer to Chapter Four]</td>
</tr>
<tr>
<td>and consider the methods with which to communicate this information effectively to</td>
<td>CAD Modelling Strategies</td>
</tr>
<tr>
<td>novice CAD users.</td>
<td>Support Material – Content</td>
</tr>
<tr>
<td></td>
<td>Definition [refer to Chapter Five]</td>
</tr>
<tr>
<td></td>
<td>Teaching and Learning Literature</td>
</tr>
<tr>
<td></td>
<td>Review [refer to Chapter Six]</td>
</tr>
<tr>
<td></td>
<td>Pilot Study Two [refer to Chapter Seven]</td>
</tr>
<tr>
<td></td>
<td>CMSS material [refer to Chapter Eight]</td>
</tr>
<tr>
<td>To establish whether the CMSS material produces a more efficient CAD user.</td>
<td>Main Study and results [refer to Chapter Nine]</td>
</tr>
</tbody>
</table>

Table 22: Focused research aims

Having identified some focused research aims, the next stage was to consider research methods and to establish which methods should be used in order to achieve the research aims.
3 RESEARCH METHODS

Overview: This chapter reviews the methodologies and methods used to guide the research, the rationale for selecting them and the limits and limitations of the data.

3.1 Introduction
The concept of CMS was defined in Chapter Two, through a review of prior art, CAD model analyses, questionnaires and a group discussion. Focused research aims were generated for the proceeding investigation. In order to ensure that the data were collected and analysed accurately, it was necessary to explore the nature and relevance of key research methodologies and methods.

The focused research aim that this study was based on can be seen in Table 23 [refer to Chapter Two, section 2.7].

<table>
<thead>
<tr>
<th>Focused research aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To identify appropriate methods for undertaking the research</td>
</tr>
</tbody>
</table>

Table 23: Focused research aim from Chapter Two [section 2.7]

It was then necessary to identify a specific research objective, as can be seen in Table 24.
## Specific research objective: Research methods

- To explore and review appropriate research methods through a review of literature

<table>
<thead>
<tr>
<th>Table 24: Specific research objective - Research methods</th>
</tr>
</thead>
</table>

The structure of this chapter can be seen in Figure 20.

<table>
<thead>
<tr>
<th>3.1 Introduction</th>
<th>3.1.1 Qualitative and quantitative research</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.1.2 Grounded Theory</td>
</tr>
<tr>
<td></td>
<td>3.1.3 Overview of research methods used</td>
</tr>
<tr>
<td></td>
<td>3.1.4 Participants and sampling strategy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.2 Exploratory Study</th>
<th>3.2.1 Prior art: CAD learning resources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.2.2 Transfer of knowledge</td>
</tr>
<tr>
<td></td>
<td>3.2.3 ‘Practiced’ CAD users</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.3 Pilot Study One</th>
<th>CAD model analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group discussion</td>
</tr>
<tr>
<td></td>
<td>Literature review</td>
</tr>
<tr>
<td></td>
<td>Self-completion questionnaire</td>
</tr>
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<td></td>
<td>t-test</td>
</tr>
</tbody>
</table>

| 3.4 Teaching and Learning |  | |
|----------------------------| | |
| 3.5 Pilot Study Two       |  | |
| 3.6 Main Study and Results|  | |
| 3.7 Summary               |  | |

Figure 20: Structure of the chapter
3.1.1 Qualitative and quantitative research

The act of undertaking ‘research’ is a vast and subjective topic and much advice is available on ‘good practice’. There are many skills and attributes that are associated with ‘good research’, as noted by Denscombe [2002:7], including ensuring that it has been completed thoroughly, precise measurement, careful record keeping and keeping an open mind [Ibid].

There is also much debate surrounding the issues concerned with the collection of qualitative and quantitative data [Bryman 2004, Coffey & Atkinson 1996, Miles & Huberman 1984]. The strengths and weaknesses of both approaches have been summarised in Table 25. It was believed that by using both methods to collect the data in as many cases as possible (also known as ‘triangulation’ [Dawson 2006:21, Bell 2005:116, McNiff et al. 2003:69]), it was possible to overcome the weaknesses of each individual aspect [Dawson 2006:21]. McNiff et al. [Ibid] note that by using this approach the researcher can ‘...obtain data from more than one source to use as evidence to support a particular explanation’ [2003:69]. A strength of this approach was that it produced a variety of sources of information, ranging from numerical datasets to interview transcripts. This allowed the researcher to select the appropriate method or methods for different aspects of the research and to gain detailed views from the participants where necessary and appropriate statistics in other instances. It also provided a rich source of information that could be cross-checked. An obvious weakness was that the researcher needed to have a good understanding of a number of different methods and was not necessarily an expert in one particular area. In order to gain the necessary experience, substantial research was undertaken on each method selected.

There is a general agreement that instead of forming opinions and assumptions based on the literature alone, the researcher can benefit from presenting their ideas in a peer review context, or validation meeting [McNiff et al. 2003], in order to ensure that the research is carried out in a professional and thorough manner. This is an attractive prospect, because the researcher can benefit from the previous experience of other academics in the field. A peer review of the research methodologies and methods was therefore carried out during an internal departmental seminar, which was very useful, as
one of the key outcomes was the suggestion of the use of ‘triangulation’ within the research, as discussed above.

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Qualitative research</th>
<th>Quantitative research</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Provides detailed information about views</td>
<td>• Can be used to make generalisations about the entire population</td>
</tr>
<tr>
<td></td>
<td>• Small scale</td>
<td>• Large scale</td>
</tr>
<tr>
<td></td>
<td>• Allows all parties to be open with their answers</td>
<td>• Can take less time than undertaking qualitative research</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>Qualitative research</th>
<th>Quantitative research</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Sample size may be smaller and it may therefore be more difficult to generalise the results across the entire population</td>
<td>• Standard, structured questions may lead to bias in the results</td>
</tr>
<tr>
<td></td>
<td>• Participants can feel uncomfortable being interviewed</td>
<td>• Participants can feel uncomfortable when writing</td>
</tr>
<tr>
<td></td>
<td>• Interpretation of data can be subjective</td>
<td>• Less contact with the participant [Dawson 2006:15]</td>
</tr>
</tbody>
</table>

Table 25: Qualitative and quantitative research

3.1.2 Grounded Theory

In order to gain detailed information relating to CMS, a grounded theory approach was used [Bell 2005, Piantanida et al 2004, Strauss & Corbin 1999, Strauss & Corbin 1998, Glaser & Strauss 1967], which sought to discover emerging themes, as opposed to specifically testing a hypothesis. This was particularly relevant in the ‘Exploratory Study’ [refer to Chapter Two], where little literature existed on the subject of CMS, as well as in the content definition stages of the research [refer to Chapter Five]. This approach was used specifically when using questionnaires, or when undertaking interviews and group discussions, as detailed in Figure 21.

Grounded theory [Ibid] is an extremely popular research method within the field of education [Dawson 2006:19], as the theory that is generated is founded in data. A key
strength of this grounded theory approach was the ability to draw themes from the qualitative data. Also, due to the nature of grounded theory, the interviews and questionnaires became more focused as each session was completed and through the continual process of reading around the topical issues. However, when different iterations of a questionnaire or interview were used, the questions that were asked may not have been consistent across the whole dataset, which can be seen as a weakness of this method. Nevertheless, the quality of the new information that was generated was considered to be more focused and relevant having used a grounded theory approach.
3.1.3 Overview of research methods used

Combined with the relevant research methods, the methodologies noted above provide the guiding principles for the research. These are summarised in Table 26 and explored further within this chapter.
### Research objectives

<table>
<thead>
<tr>
<th>Specific research objectives/questions</th>
<th>Data collection methods</th>
<th>Data analysis methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a - To explore and define the notion of CMS [refer to Chapter One, section 1.5]</td>
<td><strong>To explore and define the notion of CMS through the use of CAD model examples and a review of literature</strong></td>
<td>• CAD exercises as case study</td>
</tr>
<tr>
<td></td>
<td><strong>To develop CMS through a review of literature and existing CAD learning resources</strong></td>
<td>• Group discussions [McDonagh &amp; Bruseberg 2000]</td>
</tr>
<tr>
<td></td>
<td><strong>To confirm the emergent theories from the literature through dialogues with ‘practiced’ and ‘novice’ CAD users</strong></td>
<td>• Literature searches</td>
</tr>
<tr>
<td></td>
<td>• CAD model analysis</td>
<td>• Statistical analysis including t-tests, descriptive statistics (e.g. mean, standard deviation)</td>
</tr>
<tr>
<td></td>
<td>• Group discussions [McDonagh &amp; Bruseberg 2000]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Literature searches</td>
<td></td>
</tr>
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<td></td>
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</tr>
<tr>
<td>1b - To further define the research area [refer to Chapter One, section 1.5]</td>
<td><strong>To explore and define the notion of CMS through the use of CAD model examples and a review of literature</strong></td>
<td>• CAD exercises as case study</td>
</tr>
<tr>
<td></td>
<td><strong>To develop CMS through a review of literature and existing CAD learning resources</strong></td>
<td>• Group discussions [as above]</td>
</tr>
<tr>
<td></td>
<td><strong>To confirm the emergent theories from the literature through dialogues with ‘practiced’ and ‘novice’ CAD users</strong></td>
<td>• Literature searches</td>
</tr>
<tr>
<td></td>
<td>• CAD model analysis</td>
<td>• Statistical analysis [as above]</td>
</tr>
<tr>
<td></td>
<td>• Group discussions [as above]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Literature searches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Questionnaires [as above]</td>
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<td></td>
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<tr>
<td>2 - To generate an accurate description of what should be included in the CMSS material and consider the methods with which to communicate this information effectively to novice CAD users [refer to Chapter Two, section 2.7]</td>
<td><strong>To discover whether novice CAD users adopt different strategies to model the same part</strong></td>
<td>• CAD exercises as case study</td>
</tr>
<tr>
<td></td>
<td><strong>To establish what factors affect the strategy that is chosen to model a part</strong></td>
<td>• Group discussions [as above]</td>
</tr>
<tr>
<td></td>
<td><strong>To define specific content that should be included in the CMSS material</strong></td>
<td>• Literature searches</td>
</tr>
<tr>
<td></td>
<td><strong>To define the prerequisite knowledge that the learner would need in order to implement the CMSS material</strong></td>
<td>• Questionnaires [as above]</td>
</tr>
<tr>
<td></td>
<td><strong>To consider the key approaches to teaching CAD</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>To examine the principles of blended learning with a view to providing an engaging medium for all learners</strong></td>
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<tr>
<td></td>
<td><strong>To describe the process that incorporates this information into the CMSS material</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>To generate feedback about the CMSS material from a range of CAD users</strong></td>
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<tr>
<td></td>
<td><strong>To develop a final version of the CMSS material, for use within the main PhD trial</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Before and after study [Kumar 1996]</td>
<td></td>
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<tr>
<td></td>
<td>• CAD exercises</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Questionnaires [as above]</td>
<td></td>
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<tr>
<td></td>
<td>• CAD model analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Coding and clustering [as above]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Statistical analysis [as above]</td>
<td></td>
</tr>
</tbody>
</table>

Table 26: Overview of research methods used
In terms of selecting the participants, the sampling strategy was paramount to the accuracy of the conclusions drawn within the research [Kumar 1996:19].

3.1.4 Participants & sampling strategy

With regard to sample size, Fowler [2009:44] suggests that ‘A sample of 150 people will describe a population of 15,000 or 15 million with virtually the same degree of accuracy, assuming that all of the other aspects of the sample design and sampling procedures are the same.’ [2009:44]. McCrossan [1991] suggests that it is important to ensure that a relevant representative sample is selected, so that the researcher can apply the conclusions to the entire population [Ibid:6]. A similar approach to that noted by McCrossan was used within this research, in that a representative sample was used. However, the sample size was generally very small, so caution was taken when making claims relating to the entire population. A number of probability and purposive sampling strategies were used until ‘saturation point’ was reached [Glaser & Strauss 1967:111] (i.e. no better new knowledge was emerging), as noted by Dawson [2006:50-51], including:

- **Convenience sampling**, where participants were chosen within Loughborough University due to time and cost limitations.
- **Quota sampling**, which ensured that all groups were represented (e.g. a number who had used Pro/DESKTOP and a number who had not).
- **Quasi-random/systematic sampling**, which ensured that a ‘random’ selection of items were selected from a list (e.g. every third CAD model).
- **Theoretical sampling**, where the sample was selected due to an emerging theory (e.g. only Pro/DESKTOP users being involved).

Advantages of using a sample survey over the entire population are discussed by McCrossan [Ibid:5] and include being able to collect more detailed information, having more direct control over the data collection and therefore higher quality data. Also, using a sample survey was more cost effective and practical than surveying the entire population, so the research could therefore be carried out on a more regular basis. It should be noted that a convenience sampling was also used throughout the ‘Exploratory
Study’ as the participants were selected from undergraduate students at Loughborough University due to time and cost limitations. It should also be noted that any sampling strategy is open to inaccuracies and that generalisations made from the results should take into account the margin for error.

For all research involving participants, it was necessary to consider seeking ethical approval and to work to a code of ethics [Dawson 2006:152-153]. Therefore, the University’s ethical guidelines for conducting research with human participants was followed throughout the research. This included respecting the anonymity and confidentiality of the participants, as they were often providing information in confidence, especially in relation to their own experiences of CAD education. It was also necessary to be open and honest with the participants, so that they had a clear understanding of what the goal for each session was and what the information collated would be used for. A summary of all participants involved in this research can be found in Appendix 1.

The remainder of this chapter explores the research methods selected for each study, the rationale for selecting each method and the methods that were discounted.

### 3.2 Exploratory Study

The Exploratory Study, detailed in Chapter Two, aimed to explore and define the notion of CMS and therefore further define the research area (research objectives 1a and 1b). It also gave the researcher the opportunity to produce a research strategy, gain knowledge on the data collection and analysis methods and reflect on the practices selected.

#### 3.2.1 Prior art: CAD learning resources

At the outset of the research, it was necessary to establish whether the notion of effective CMS had been identified in previous literature. It was also necessary to learn more about the existing material in the field and to generally critique the prior art. Therefore, a literature review was undertaken of literature relating to CMS as well as existing CAD material.
The review was based on systematic literature searches, using a set of databases, which enabled the researcher to establish prior art in the field, identify the gaps in knowledge and position the research within the context of others. Through the use of this highly structuralistic strategy, the researcher was able to ensure that the search targeted specific keywords and, more importantly, could be repeated as new material was published over the course of the research project. The process that was used is summarised in Table 27, but can be seen in detail in Appendix 2, which includes annotated screen prints of the databases.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two databases were created to log the Subject Resource Directories Searches and the Loughborough University OPAC searches. Several different sources were used, including online databases such as Metalib and OPAC, various newspaper articles and library CD-ROMS. Searches were also carried out using Internet search engines such as ‘Google’, as well as more specific databases such as ‘Web of Science’. Further searches were carried out in Loughborough University Library with monthly journals, such as ‘Time-Compression Technologies’, ‘CAD User’ and ‘Design News’. The British Library was also used to locate items that were difficult to acquire from other sources. Several mailing lists were also subscribed to, including the ‘PhD Design List’ [<a href="http://www.jiscmail.ac.uk/archives/phd-design.html:2007">http://www.jiscmail.ac.uk/archives/phd-design.html:2007</a>], the ‘DRS List’ [<a href="http://www.jiscmail.ac.uk/lists/DRS.html:2007">http://www.jiscmail.ac.uk/lists/DRS.html:2007</a>] and the ‘Design Research’ list [<a href="http://www.jiscmail.ac.uk/lists/design-research.html:2007">http://www.jiscmail.ac.uk/lists/design-research.html:2007</a>]. These mailing lists provided an on-going source of up-to-date information and links.</td>
</tr>
<tr>
<td>2</td>
<td>A list of keywords were identified (with special care being taken to look at the synonyms and related terms, American terms, spellings, word endings and abbreviations), which were then entered into the databases.</td>
</tr>
<tr>
<td>3</td>
<td>Searches were undertaken and useful results logged.</td>
</tr>
<tr>
<td>4</td>
<td>The suitability of the item was then taken into account, which included looking at the date the article was written, whether the article had been updated (e.g. if it originated on the Internet), the article’s audience (i.e. language of article – basic/technical) and whether the focus of the article was popular or academic. It was also necessary to consider the author, to discover their academic credentials, their position within the field and also the thoroughness of their work.</td>
</tr>
<tr>
<td>5</td>
<td>Suitable items were then sourced and used as appropriate.</td>
</tr>
</tbody>
</table>

Table 27: Literature search strategy

The strength of this methodology meant that searches would not be repeated unnecessarily, could be referred to at a later date and could be repeated later in the research programme.
The literature review on CMS prior art can be found in Chapter Two, Section 2.3.

3.2.2 Transfer of knowledge

As noted in Chapter One, Wiebe [2000:435] suggests that users’ syntactic and semantic knowledge can transfer between 3D CAD packages. Wiebe [Ibid] suggested that the ‘transfer’ of knowledge (and potentially CMS knowledge) would happen when the learner had mastered the basics of the package, although it was unclear what the ‘basics’ of mastering the CAD package were and what exactly transferred between CAD packages. Therefore, in order to investigate whether knowledge transferred between CAD packages, it was firstly necessary to select a group of participants who had varied use of a previous CAD package (Pro/DESKTOP). It was then necessary to establish whether the participants had used Pro/DESKTOP significantly, non-significantly or not at all. Then, by comparing the difference in marks awarded for an assignment, it was possible to establish whether previous use of Pro/DESKTOP affected the participants’ performance in the assignment. Therefore, a purposive convenience sampling strategy was used to target a self-completion questionnaire [Bell 2005, Brace 2004, McNiff et al. 2003, Oppenheim 1992] at Year One undergraduates at Loughborough University to establish the participants’ prior use of CAD.

A questionnaire was used as it allowed the researcher access to a large number of participants and collect quantitative data in a relatively short period of time. In a general sense, questionnaires are useful for quickly identifying generic trends that could potentially be applied to the whole population. A limitation of the use of questionnaires includes the potential for a poor response rate, as well as some participants not feeling comfortable when responding to open questions (or even treating the questionnaire superficially). However, the weaknesses were overcome by providing the opportunity for the participant to verbalise their answer if they did not feel comfortable writing it and by handing out questionnaires in person.

In terms of the design of the questionnaire, the form and copy were designed to be as impartial as possible. The starting point was to consider the research objectives and determine a set of key questions that needed to be answered [Brace 2004:11]. The following points were considered:
• Ensuring that the respondent understood the questions properly [Ibid:15]

• Ensuring that the response from the participant was recorded accurately and completely [Ibid:17].

• Ensuring that the design of the questionnaire was interesting to; a) keep the respondent’s attention [Ibid:17–8, Oppenheim 1992:122] and b) to ensure a high percentage return rate.

• Ensuring that the questionnaires were impartial so as not to lead people to a particular response.

All questionnaires included an opening paragraph to provide the participant with an explanation of the background of the research. Questions were split into several different sections and were numbered so that the results could easily be transferred onto SPSS for statistical analysis [refer to Appendix 3 for an example questionnaire].

Guidance from Dawson [2006:100] for questionnaire design was followed, including making sure that the questionnaire was as short as possible, not assuming knowledge, keeping complex questions at the end, using a mixture of question formats, avoiding leading questions and providing all possible responses in closed questions [Ibid].

The questionnaires were analysed using the Coding and Clustering method [Miles & Huberman 1984] for the open question responses and quantitative analysis in Microsoft Excel and SPSS for the closed question responses.

From the questionnaire, it was possible to split the participants (n=120) into distinct groups, and to take a mean ‘mark’ for each group (from their coursework assignment). An independent samples t-test was then used to compare the difference between the mean marks from the groups, to determine whether the difference in the marks that the participants were awarded was statistically different. Pallant [2001], Field [2000], Kinnear & Gray [2000] and Einspruch [1998] provided an invaluable source of information on manipulating the data using SPSS. However, it should be noted that the t-test was conducted at one university only, therefore, the results are not a representation of the entire population.
The dataset could also have been collected using interviews, although this was rejected as it would have been too time consuming to interview all of the participants. Another method that was considered for the analysis of the data included using a one-sample t-test, which would have compared how the mean of one sample compared to a fixed value (for example, the mean mark for the past five years of the module). However, this was rejected due to issues with the validity of the data, as the participants would have been using different versions of the software and would have been taught by different lecturers.

The questionnaire and t-test sections referenced above can be found in Chapter Two, Section 2.4.1.

3.2.3 ‘Practiced’ CAD users

The emergent theories from the literature pointed at three key approaches relating to modelling on CAD, which included the ‘feature-based’ approach, the ‘overarching’ approach and the ‘detailed’ approach. In order to explore those approaches further, it was necessary to look in depth at the CAD models produced by the ‘practiced’ CAD users. In particular, it was important to establish whether there were any implications relating to the way that the model had been created, or whether there were any benefits of using one strategy over another.

A theoretical purposive sampling strategy was used to select participants who had been using CAD regularly for three years or more. Additionally, it was necessary to select participants who had chosen to model comparable products. This allowed the researcher to compare strategies used to model similar products. The analysis consisted of looking in detail at the number of parts and sub-assemblies that were created, the general approach and how the parts were constructed. The CAD model analysis was logged in a report using screen prints and detailed descriptions [refer to Appendix 5 for an example analysis]. In some examples, a timed test was undertaken by the researcher to establish how much time could have been saved using one approach over another. This involved the researcher modelling each part three times and using the mean timing to demonstrate the time implications of the use of different strategies. The significance of modelling each part three times was to counteract the maturation effect. For example, it
is likely that the first attempt at modelling the part took slightly longer than the third attempt, as the researcher was more used to the GUI and features. However, using an average time was sufficient within this section of the research as the purpose of this timed test was demonstrative. Presentation boards containing the results of the analysis were then produced, which presented the differences between the models.

A self-completion questionnaire [Bell 2005, Brace 2004, McNiff et al. 2003, Oppenheim 1992] was then used to establish whether the themes established through the review of literature and CAD model analysis were true across the whole module. Again, using a questionnaire allowed the researcher to access a large number of participants and collect quantitative data quickly and efficiently. The questionnaires were analysed using the Coding and Clustering method [Miles & Huberman 1984] for the open question responses and quantitative analysis in Microsoft Excel and SPSS for the closed question responses.

A group discussion [McDonagh & Bruseberg 2000] was also used to again, look in more depth at the themes found through the review of literature, CAD model analysis and questionnaires. Group discussions, or ‘focus groups’, as Dawson [2006:31] suggests, have a number of advantages and disadvantages. However, it is believed that the disadvantages of using this method (such as some people being uncomfortable or nervous in a group setting and other people contaminating an individual’s view) were counteracted [refer to Table 28]. Advice was sought from the Module Leader at Loughborough University, to select the most advanced Pro/ENGINEER CAD users within the group in order to help to define the notion of CMS and to explore issues related to modelling on CAD from a ‘practiced’ CAD user’s standpoint. The group discussion allowed the six participants to talk in depth on key issues as they were raised by both the researcher and the group. It was possible to capture detailed emotive information on the topic that may not have been possible using a questionnaire alone.

In order to ensure that the group discussion was recorded accurately, a group discussion summary form was completed [Dawson 2006:113], and the discussion was transcribed in full. The data were coded and clustered [Miles & Huberman 1984] by reading the transcript in the first instance and then listing key categories. Codes were then assigned
to the categories, like codes were clustered and themes were drawn from the data [refer to Appendix 4 for an example of a coded transcript]. Strengths of the ‘coding and clustering’ method included the ability to draw detailed themes from the data and to compare like transcripts together. An obvious weakness of this method was that the codes assigned to the data were subjective. However, a third party was asked to assign codes to the data to ensure that any bias was counteracted.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
<th>How disadvantages were counteracted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can receive a wide range of responses during one meeting</td>
<td>Some people may be uncomfortable in a group setting and nervous about speaking in front of others</td>
<td>Each participant was each given a chance to talk individually. This also ensured that all participants contributed</td>
</tr>
<tr>
<td>Participants can ask questions of each other, lessening impact of researcher bias</td>
<td>Not everyone may contribute</td>
<td></td>
</tr>
<tr>
<td>Helps people to remember issues they might otherwise have forgotten</td>
<td>Other people may contaminate an individual’s view</td>
<td>Although it was apparent that this weakness was difficult to overcome, it is believed that in all of the group discussions undertaken within the research, a balanced and thoughtful overview of the issues was achieved</td>
</tr>
<tr>
<td>Helps participants to overcome inhibitions, especially if they know other people in the group</td>
<td>Some researchers may find it difficult or intimidating to moderate a focus group</td>
<td>The researcher did not find it intimidating to moderate the group and measures were taken to ensure that the group did not digress, as noted by Dawson [2006:81]</td>
</tr>
<tr>
<td>The group effect is a useful resource in data analysis</td>
<td>Venues and equipment can be expensive</td>
<td>The venues and equipment were all readily available at Loughborough University</td>
</tr>
<tr>
<td>Participant interaction is useful to analyse</td>
<td>Difficult to extract individual views during the analysis</td>
<td>Individual views were extracted during the analysis by asking each participant to state their name before speaking during the group discussion</td>
</tr>
</tbody>
</table>

Table 28: The focus group method - Advantages and disadvantages [Dawson 2006:31]
Another method that was considered within the Exploratory Study was to contact industry experienced CAD users to understand the strategies that they implemented. However, this was rejected as it was believed that the participants who had been using Pro/ENGINEER for three or more years at university were equally ‘expert’, as they had been using the software on a regular basis in a design context for over three years. However, it should be noted that the CAD user participants were therefore not a representation of industry experienced CAD users. Also, the direct overt participant observation method was considered in order to log the strategies that were being used to create the participants’ CAD models. However, this was rejected because it would not have been possible to access the participants at all times during the project, as many of them undertook their CAD modelling in their own time, often at home.

The CAD model analysis, questionnaire and group discussion sections referenced above can be found in Chapter two, Section 2.4.2.

3.3 Pilot Study One

During the Exploratory Study, it was found that there were three distinct approaches to modelling on CAD (the ‘feature-based’ approach, the ‘overarching’ approach and the ‘detailed’ approach). The research aimed to establish the extent to which CMS could be taught to novice CAD users. It was, therefore, important to understand what the contributing factors were to the selection of a strategy or approach (both effective and non-effective) when modelling on CAD. It was then necessary to consider some solutions for the CMSS material that would help to prevent the participants feeling ‘forced’ to select a certain CMS (research objective 2).

Therefore, a convenience, purposive sampling strategy was used to select the participants in their first and second years on Industrial Design and Technology at Loughborough University. All students in Year One and Two (n=240) were asked to volunteer for the trial and ten participants agreed to take part. In order to confirm that the CAD users selected different approaches to modelling the same part, a CAD exercise was set, which ensured that all participants were modelling the same part, under the same conditions and in the same amount of time. The CAD models were then analysed [refer to Appendix 5 for an example analysis] and having confirmed that
different strategies were selected, a group discussion [Dawson 2006, McDonagh & Bruseberg 2000] was undertaken to establish the contributing factors to the participants selecting one strategy over another. The group discussion allowed the participants to talk in depth on key issues as they were raised.

A group discussion summary form was completed [Dawson 2006:113] and the discussion was transcribed in full. The data were then coded and clustered [Miles & Huberman 1984 - refer to Appendix 4 for an example of a coded transcript].

A group discussion was selected over interviews as the CAD exercise was held as a group, and the researcher believed that it would be beneficial to capture the participants’ feedback immediately after the CAD exercise. If interviews were used, the participants would have been given individual times to attend the interview after the exercise, and important information may have been forgotten.

It should be noted that the sample size for this study was relatively small, so the information gathered is not an accurate representation of the entire population.

This study can be found in Chapter Four.

3.4 Teaching and Learning
The research aimed to develop effective CAD Modelling Strategies (CMS) and investigate the impact of these strategies on novice CAD users. It looked to establish whether this knowledge would enable novice CAD users to capture their design intent effectively, whilst being able to make key design changes to their model. It was therefore important to establish what the key approaches to teaching CAD were and how the CMSS material could be most effectively communicated to product designers learning to use CAD (research objective 2).

A literature review was therefore undertaken relating to teaching and learning CAD and blended learning. Again, the review was based on systematic literature searches, using a set of robust databases, as described in Section 3.2.1. Additionally, Year One CAD
lectures were observed by the researcher on a weekly basis between October 2002 and July 2003 (one academic year) in order to establish what techniques were being used, and how they differed between semesters, when the learner had become more practiced in CAD.

Another method that was considered was to review CAD teaching at other universities. However, the logistics of the study prevented the researcher reviewing CAD teaching elsewhere.

The literature review on CMS prior art can be found in Chapter Six.

### 3.5 Pilot Study Two

Having established that there were three key CAD modelling approaches [refer to Chapter Two], which were explored in detail in Chapter Five, it was necessary to use all of the research to date to trial a number of different iterations of the CMSS material, before the main PhD trial (research objective 2). Therefore, various trials were set up in order to test the material over the course of one year in order to ensure that key messages were put across successfully to the target audience, including one formal trial using A-level students. The formal trial included a group discussion (to establish the extent of previous CAD use) and a questionnaire (to evaluate the material and generate quantitative statistics).

The aim of the trails was to test the methods with which the materials were presented (e.g. Print, Computers, Group Work and Tutorials) as well as the content of the material. Access was available, through Loughborough University, to a considerable number of Pro/DESKTOP users of varying abilities. A theoretical, purposive sampling strategy was used to select the participants in the formal evaluation of the content.

Generally, the CMSS material was implemented to the participants and feedback recorded. A self-completion questionnaire [Brace 2004] was used to collect data in the formal evaluation. In order to ensure that the group discussion was recorded accurately, a group discussion summary form was completed [Dawson 2006:113] and the
discussion was transcribed in full. The data were coded and clustered [Miles & Huberman 1984 - refer to Appendix 4 for an example of a coded transcript]. The questionnaires were also analysed using the Coding and Clustering method [Miles & Huberman 1984] for the open question responses and quantitative analysis in Microsoft Excel and SPSS for the closed question responses.

It should be noted that the early trials of the material did not generate formal feedback, rather the material was trailed in an informal environment and notes were made by the researcher regarding positive and negative aspects. Formal feedback was considered for all of the trials, although the context in which the material was being used and the nature of the feedback required suited an informal environment.

This study can be found in Chapter Seven.

3.6 Main Study and Results
As noted previously, the research aimed to establish the extent to which CMS could be taught to novice CAD users, through a combination of three key approaches (the ‘feature-based’ approach, the ‘detailed’ approach and the ‘overarching’ approach). The Main Study was used to test the final version of the CMSS material (research objective 3), and was carried out in two phases – the implementation of the final version of the CMSS material and the evaluation of the CMSS material (including a timed CAD exercise). The methods used therefore varied accordingly. In the implementation phase, a ‘before and after’ study was used. In the evaluation phase, interviews, questionnaires and CAD model analyses were used.

The ‘before and after’ study [Kumar 1996] approach was selected in order to ensure that there existed a ‘control’ population with which to compare the intervention to (the CMSS material). This study consisted of a two-phase sampling strategy [Kumar 1996]. Primarily, a number of participants were selected to take part in the research using a purposive sampling strategy [Dawson 2006:50-51]. The participants were then analysed and a ‘matching’ population was selected. The participants were ‘matched’ using four
key criteria including the CAD package that they had used, their use of the CAD package, their mark for the initial perfume bottle assignment and their A-level course.

It should be noted that the Control Group were in the same building and general CAD lectures as the CMS Group. However, the risk of the Control Group accessing the CMS information was minimized in the following ways:

• Only allowing the CMS Group to attend the initial briefing and support sessions
• Including a login screen to access the online CMSS material
• Asking the CMS Group not to share information with others in the cohort

Additionally, the nature of the materials was such that without a full blend of Print, Computers, Group Work and Tutorials, the online section of the material would have been of little use to the Control Group. It would not have been feasible for the researcher to use a Control Group at another university, as there would have been too many variables (e.g. different lecturers, content, pace of learning, computers and potentially software), and the case study results would not have been as relevant.

Interviews and self-completion questionnaires [Brace 2004] were used within the second phase of the Main Study to gain qualitative and quantitative data regarding the feedback of the CMSS material. Additionally, CAD exercises were paramount to this part of the research and it was therefore important to ensure that a consistent approach was used to analyse the CAD models produced by the participants. The process used to examine the CAD exercises was based on the theory of observation [Dawson 2006, Bell 2005, McNiff et al. 2003] combined with CAD model analysis. This allowed the researcher to consider in detail the strategy used for the CAD modelling task through direct overt participant observation and deconstruction of the CAD models. It also produced accurate timings relating to how a CAD model had been created.

In terms of analysing the data, the interviews were then transcribed in full and the data were coded and clustered [Miles & Huberman 1984 - refer to Appendix 4 for an exampled of a coded transcript]. The questionnaires were analysed using the Coding
and Clustering method [Miles & Huberman 1984] for the open question responses and quantitative analysis in Microsoft Excel and SPSS for the closed question responses.

Many methods were considered, but not used within the main study, which related to both the sampling strategy and the use of different research methods. With regard to the sampling strategy, testing the CMSS material on the entire year and testing the CMSS material on half the year were considered, although they were subsequently rejected as it would have been difficult to make a comparison with a suitable and valid Control Group. Other research methods discounted within the main study included setting the users a specific CAD task, where one specific product would be modelled. Advantages of using this method included the ability to control the level of difficulty of the product being modelled, and being able to make exact comparisons between models. However, this was rejected as it would have become an additional assignment for the participants, which could have resulted in a lower participant take-up level, as well as less time being spent on the project. Another option was to conduct the study with an additional university, which would have produced a broader range of participants. However, this was rejected as the teaching methods would inevitably vary between universities, and therefore, comparisons could not be made. Setting the participants a design task, rather than a reverse engineering task was also considered, which would allow for more design development. However, this was rejected as there would have been little consistency between products being modelled, and it would therefore become difficult to make comparisons between the products.

It should be noted that there were some limitations relating to the methods that were selected. One relates to the sampling strategy, as if both groups were not matched accurately, or if the representative sample of the population was not selected appropriately, conclusions drawn from the data would not be as accurate. However, it is believed that the sampling strategy used was as detailed as possible, to ensure that the case study data were useful. Also, with regard to the method of direct overt participant observation, it should be noted that the participants may have felt under pressure in the presence of the video recorder and potentially not behave as they would have normally. However, it is believed that this weakness was overcome in the Main Study by
providing a relaxed environment for the participants to work in and by showing the participants what the video was recording (in this research, only the computer monitor).

This study can be found in Chapter Nine.

3.7 Summary
To summarise, a review of research methodologies was conducted to ensure that the data were collected and analysed appropriately to provide meaningful end results. Careful attention was taken to ensure that the participants used in the studies were selected in an appropriate manner and that ethical guidelines were followed.
4 PILOT STUDY ONE

Overview: This chapter reviews the first pilot study which aimed to further understand the notion of CMS with respect to the factors that contribute to the selection of a CMS.

4.1 Introduction

In Chapter Two, the notion of CMS was considered in depth and focused research aims were established for the remainder of the research. It was found, within the Exploratory Study, that there were three distinct approaches to modelling on CAD (the ‘feature-based’ approach, the ‘overarching’ approach and the ‘detailed’ approach). Although this was useful in defining the foundations for the content of the CMSS material, a further area needed to be considered, which related to what the contributing factors were to the selection of a strategy or approach when modelling on CAD. Therefore, this chapter looks to firstly confirm that CAD users select different approaches to modelling the same part [refer to Chapter Two, section 2.2], secondly, to establish the contributing factors to the selection of a specific approach to modelling on CAD (either effective or ineffective7) and finally, consider the implications of these factors on the design of the CMSS material.

The focused research aim that this study was based on can be seen in Table 29 [refer to Chapter Two, section 2.7].

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7 ‘Ineffective’ strategies can be thought of as those that use ineffective features or combinations of features to create a CAD model. An ineffective CMS will not allow designers to make changes to their design quickly and efficiently.
Focused research aim

- To generate an accurate description of what should be included in the CMSS material and consider the methods with which to communicate this information effectively to novice CAD users.

Table 29: Focused research aim from Chapter Two [section 2.7]

It was then necessary to identify specific research objectives, as can be seen in Table 30.

Specific research objectives: Pilot Study One

- To discover whether novice CAD users adopt different strategies to model the same part
- To establish what factors affect the strategy that is chosen to model a part

Table 30: Specific research objectives - Pilot Study One

4.2 Pragmatic issues

The pilot study discussed within this chapter involved two basic approaches; a CAD exercise and a group discussion [refer to Chapter Three, section 3.3]. The aim of the CAD exercise was to establish whether CAD users adopted different strategies to model the same part and the group discussion allowed the participants to discuss their rationale for selecting their CAD approach in detail.

A convenience, purposive sampling strategy was used to select participants in their first and second years on Industrial Design and Technology at Loughborough University. All students in Year One and Two were asked to volunteer for the trial and ten participants agreed to take part in the research (four from Year One and six from Year Two).
4.3 CAD modelling exercise

It was important, primarily, to find an appropriate product for the participants to model within the CAD exercise, which contained parts that could be modelled using a number of different strategies. Having created a number of potential products, it was decided to use a toy ‘tipper’ lorry within the exercise and to focus on two key parts - the ‘wheel part’ and the ‘tipper part’ [refer to Figure 22].

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**Figure 22**: Pro/ENGINEER model of the toy ‘tipper’ lorry (including wireframe models of the ‘wheel part’ and ‘tipper part’).
The CAD exercise was piloted on a Postgraduate Research Student, with relatively little CAD experience, to test the timings and feasibility of the exercise. The participants were initially presented with engineering drawings of the lorry and a physical model of the lorry. The trial lasted two hours and the participants were given forty five minutes to model each part. Through a thorough analysis of the parts modelled, it was apparent that the participants had modelled the parts using very different strategies, some of which could be classed as ‘ineffective’, as it would be very difficult to make key design changes to them [refer to Appendix 5 for an example CAD model analysis].

4.4 Influencing factors
In order to examine what factors affected the strategy that the participants selected to model the parts and later, the pedagogical implications of the findings, the participants were involved in a group discussion [refer to Chapter Three, section 3.3.3]. The discussion was then transcribed, coded and clustered [Miles & Huberman 1984] and eight clear themes emerged that related to the way that the participants had modelled the parts. It was very interesting to discover that many of the participants felt ‘forced’ to select a certain strategy, perhaps because they had had a negative experience of using a specific feature in the past. It was obvious that such influencing factors could have resulted in them having modelled their part ineffectively. However, through the CMSS material, it may be possible to negate some of these problems. Table 31 shows the influencing factors to selecting a CMS, and how the CMSS material could be designed to negate the learners’ feeling of being ‘forced’ to proceed with a particular (possibly ineffective) strategy.
<table>
<thead>
<tr>
<th>Influencing factors to selecting a CMS</th>
<th>Details</th>
<th>Potential solutions in the CMSS material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bad experiences</td>
<td>• The participants noted that if a feature had not worked well before, they would be ‘put-off’ and be less likely to use it again.</td>
<td>• By providing the learners with support when modelling on CAD, it may be possible to resolve the problems they have with a particular feature, to allow them to use it confidently in the future.</td>
</tr>
<tr>
<td>2. Creating the part in reality</td>
<td>• The participants sometimes selected their strategy by considering how it was created in reality.</td>
<td>• Relating the product being modelled on CAD to a ‘real-life’ example may provide comparable examples to the learner, in terms of visualisation and help them to visualise their CMS.</td>
</tr>
<tr>
<td>3. Downstream activities</td>
<td>• Many participants suggested that their strategy was dependant on the downstream activities of the CAD model. For example, if they were simply using the CAD model for a rendering, they would not be worried about ensuring that the dimensions were correct. Instead, they would model the product so that it looked correct, perhaps even from one angle.</td>
<td>• By showing the learner the potential to exploit an accurate CAD model, it may help them to select an effective strategy from the outset.</td>
</tr>
<tr>
<td>Influencing factors to selecting a CMS</td>
<td>Details</td>
<td>Potential solutions in the CMSS material</td>
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</tbody>
</table>
| 4. Knowing that modifications would have to be made to the model | • The participants mentioned that if they knew that modifications would have to be made, they would plan how they would model the part in more detail, possibly using sketches.  
• They also mentioned that they would make sure that everything was connected parametrically within the CAD model. | • By providing the learners with a formal planning process, it may help them to consider the modifications that would have to be made to the model.  
• Including information relating to shared geometry and shared references may make it easier for the users to modify their model. |
| 5. Memory recollection | • Some of the participants mentioned that the strategy used to model the parts was the only approach that they could remember, or they adopted a ‘trial and error’ method of modelling the parts. | • By providing the learners with a planning process at the outset of the modelling task, it may help the learners to be informed of a number of different options available to them when selecting a CMS. |
| 6. Perception of the complexity of the features | • Some participants noted that they might try to use a more ‘complicated’ tool if the model needed to be very accurate, rather than using a ‘simple’ tool that would create a less accurate model.  
• The reason that they would not select a more ‘complex’ feature initially, was that they believed that the more complex the feature, the more likely it is to ‘go wrong’ and that with the simpler features, they are less likely to receive error messages. | • Giving the learners clear examples of how to use features that are perceived as more ‘complicated’ (such as the shared geometry features) may build their confidence to make an informed choice.  
• Showing the learners how to recover from error messages [refer to Chapter Two] may build their confidence and help them to make an informed choice. |
### 7. Time

- Some participants mentioned that if the CAD part of the project had a ‘low’ weighting in terms of the assessment, then they would not want to spend a lot of time modelling the part using a complex strategy (especially if that involved learning a new method of modelling the part).
- If time was a consideration, the participants mentioned that they may choose the easiest method with which to model the part, to ensure that they would finish the project on time.
- Some participants suggested that they would use a method that they understood was not the most effective one, if it meant not having to spend time learning how to use an alternative one.

- By showing the learners that although an ‘easier’ method may appear to save them time at the outset of the project, this may have vast implications on the time at a later stage in the project if the part needed to be modified, it could encourage them to make an informed choice about their CMS.
- Showing the learners that by investing time learning an alternative method, it could allow them to make changes to their product more easily at a later stage in the project, could again encourage them to make an informed choice about their CMS.

### 8. Working as a team

- Some of the participants commented that if they were working as a team, they would try to model to the complexity that the team as a whole was comfortable with.

- By providing all learners with the knowledge to model on CAD at a certain level, the learners may feel more inclined to use the most effective strategy, as they would know that other members of their team have been trained to the same level.

<table>
<thead>
<tr>
<th>Influencing factors to selecting a CMS</th>
<th>Details</th>
<th>Potential solutions in the CMSS material</th>
</tr>
</thead>
</table>
| 7. Time                                | - Some participants mentioned that if the CAD part of the project had a ‘low’ weighting in terms of the assessment, then they would not want to spend a lot of time modelling the part using a complex strategy (especially if that involved learning a new method of modelling the part).  
  - If time was a consideration, the participants mentioned that they may choose the easiest method with which to model the part, to ensure that they would finish the project on time.  
  - Some participants suggested that they would use a method that they understood was not the most effective one, if it meant not having to spend time learning how to use an alternative one. |
| 8. Working as a team                   | - Some of the participants commented that if they were working as a team, they would try to model to the complexity that the team as a whole was comfortable with. |
|                                        | - By providing all learners with the knowledge to model on CAD at a certain level, the learners may feel more inclined to use the most effective strategy, as they would know that other members of their team have been trained to the same level. |

**Table 31: Influencing factors in selecting a CMS**
4.5 Summary

To summarise, a pilot study was undertaken to learn more about the factors that influence a CAD users’ choice of strategy. Ten participants of differing CAD abilities were selected to participate in ‘Pilot Study One’ and were asked to undertake a CAD exercise. The CAD exercise proved that CAD users selected a number of different strategies to model the same part. Through a group discussion with the participants regarding the factors that influenced their choice of CMS, eight key themes emerged relating to participants feeling ‘forced’ to select a certain CMS. Solutions were considered that attempted to negate each point, which have an impact on the design of the CMSS material.

A key influencing factor to the selection of a CMS is the learner’s perception of the more ‘complicated’ features, such as swept blends, shared geometry and shared references. The learner may select a more effective CMS if they have the confidence to make an informed choice from all of the basic features, including those considered to be more ‘complicated’. It may be possible for the learner to gain confidence in using these features by providing them with examples that use the features, or by providing them with step-by-step guides. Of importance is also showing the learner how to recover from error messages, so that they can resolve any problems with the CAD model using the error message recovery screen, as opposed to starting the model again using a different strategy. Again, this was highlighted in Chapter Two. However, if this fails, it is clear that participants require one-to-one support in order to resolve specific problems, to allow them to proceed in the same way more confidently in the future. This was particularly important, as some participants suggested that they were ‘put off’ from using a specific feature by a feature ‘going wrong’, which would stop them using it again in the future.

Therefore, in order to become an effective CAD modeller, it is proposed that it is necessary to encourage the learner to use an effective CMS, regardless of the time implications. The learners could be encouraged to use a more effective CMS by showing them that although an ‘easier’ method may appear to save them time at the outset of the project, it may have vast implications on the time it takes to modify a part at a later stage in the project. This could be achieved by providing a group with a
number of strategies with which to model the same product and asking them to change the product at a later point, so that the group witnesses the implications of an effective strategy versus an ineffective strategy when modifying the model. By asking the learner to consider any modifications that will be needed to the model at the beginning of the modelling process, it may encourage them to consider how parts interact with each other and whether it would be necessary to consider the use of shared geometry and/or references. By creating a ‘planning’ stage to the CAD modelling process, where a number of different options are presented to the user (in terms of strategies and features), it may help the learner to make an informed choice about their CMS.

Also of interest was the notion of relating the product being modelled on CAD to a ‘real-life’ example, which may provide comparable examples to the learner in terms of visualisation and, eventually, the selection of an effective CMS. Also, some participants suggested that the act of working in a team would affect their CMS, as they would only work to the same level as the rest of the team. However, by providing all learners with the knowledge to model on CAD at a certain level, the learner may feel more inclined to use the most effective strategy, as they would know that other members of their team would have been trained to the same level.

The next stage was to begin to define the content of the CMSS material. In particular, a more definitive description of the three key approaches noted in Chapter Two is required (the ‘feature-based’ approach, the ‘overarching’ approach and the ‘detailed’ approach). It is also necessary to clearly define the target audience, key learning points and constraints of the CMSS material to be designed.
5 CAD MODELLING STRATEGIES SUPPORT MATERIAL - CONTENT DEFINITION

Overview: This chapter builds on the prior art and the research that has previously been undertaken. It looks to define the foundations of the content of the CMSS material and considers the target audience, key learning points, delivery dates and constraints of the material.

5.1 Introduction

Having established that there are three distinct approaches to modelling on CAD (the ‘feature-based’ approach, the ‘overarching’ approach and the ‘detailed’ approach), it was necessary to begin to define the content of the CMSS material, using the previous research and literature as a guideline. The focused research aim that this chapter addresses can be seen in Table 32 [refer to Chapter Two, section 2.7].

Focused research aim: CMSS material - Content definition

- To generate an accurate description of what should be included in the CMSS material and consider the methods with which to communicate this information effectively to novice CAD users.

Table 32: Focused research aim from Chapter Two [refer to section 2.7]

It was then necessary to identify specific research objectives, as can be seen in Table 33.
Specific research objectives: CMSS material - Content definition

- To define specific content that should be included in the CMSS material
- To define the prerequisite knowledge that the learner would need in order to implement the CMSS material

Table 33: Specific research objectives: CMSS material - Content definition

Emergent themes were noted in Chapter Two [section 2.6], which suggested that a combination of three distinct areas relating to learning to use CAD were necessary in order to communicate *effective* CMS to novice users. This involved a consideration of the use of the three approaches, as shown in Figure 18 (the use of all basic features, the use of the ‘overarching’ approach and the use of the ‘detailed’ approach).

CAD resources that are specific to a particular piece of CAD software generally teach the ‘feature-based’ approach [refer to Chapter Two, section 2.3.1]. Therefore, it is proposed that the CMSS material should contain elements of the ‘detailed’ approach [refer to Chapter Two, section 2.3.3] and the ‘overarching’ approach [refer to Chapter Two, section 2.3.2]. Combined with the information relating to how to use all of the basic features, it is envisaged that novice CAD users will have all of the knowledge required to select an effective CMS [refer to Chapter Two, section 2.6].

5.2 Defining the content

Having established that elements of the ‘detailed’ approach and ‘overarching’ approach should be included in the prototype CMSS material, it was necessary to draft an initial overview of the knowledge that it is believed a novice CAD user must have in order to select an effective CMS.

Clearly, CAD users require different levels of sophistication in their CAD models and it was necessary to take this into account when defining the content. For example, a CAD user who is creating a mobile phone, who needs all of the parts to link parametrically requires a different level of sophistication in terms of CMS to a user who is CAD
modelling a vase. Therefore, the content for the CMSS material has been defined as per Table 34. This takes into account combinations of the use of the ‘feature-based’, ‘detailed’ and ‘overarching’ approaches and it is envisaged that the majority of the CAD models that product designers would create would fall under the ‘sharing’ strategy section, denoted by the grey shading.

<table>
<thead>
<tr>
<th>Content definition: Strategy name</th>
<th>Details of CAD model to be created</th>
<th>Uses ‘feature-based’ approach?</th>
<th>Uses ‘overarching’ approach?</th>
<th>Uses ‘detailed’ approach?</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Trial and error’ strategy</td>
<td>User does not have a clear idea of what they are creating</td>
<td>Yes</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>‘Sharing’ strategy</td>
<td>User has a clear idea of what they are creating and requires the CAD model to link parametrically with other models</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>‘Separate’ strategy</td>
<td>User has a clear idea of what they are creating, but does not require the CAD model to link parametrically with other models</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Table 34: Content definition - CMS**

It was then necessary to use the prior art and previous research to provide descriptions of the strategies noted above. A number of strategies within each approach were defined in the Exploratory Study [refer to Chapter Two], which have been shown diagrammatically in Figure 23.
A brief description of the strategies noted above (within the ‘overarching’ approach and ‘detailed’ approach) can be seen in Table 35.

It is envisaged that the learner would primarily select one of the three strategies noted in Figure 23 - the ‘trial and error’ strategy, ‘sharing’ strategy or ‘separate’ strategy. They would then be presented with differing content dependent on the route selected. For example, if, as anticipated, the learner selected the ‘sharing’ strategy, they would be presented with information relating to the ‘feature-based’ approach, ‘detailed’ approach and ‘overarching’ approach. Therefore, the remainder of this chapter describes each of the approaches and strategies noted above, using the prior art and previous research as the foundation.
<table>
<thead>
<tr>
<th>Approach</th>
<th>Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Overarching’</td>
<td>‘Duplicate part’</td>
<td>To create a copy or mirror of another part [Toogood 2006a]</td>
</tr>
<tr>
<td>approach</td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Pattern’</td>
<td>Use of the pattern feature to assemble a number of the same parts [Toogood 2006a]</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Skeleton’</td>
<td>Use of a ‘skeleton’ model that contains the key geometry [Toupin &amp; Benjamin 2002, Brown et al 2001, refer to Chapter Two]</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Symmetry’</td>
<td>Use of symmetry at a part level, e.g. to mirror one half of a car to create a whole part [refer to Chapter Two]</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td>‘Detailed’</td>
<td>‘Pattern’</td>
<td>Use of pattern to create numerous copies of one feature [Toogood 2006a]</td>
</tr>
<tr>
<td>approach</td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Profile-profile’</td>
<td>Sharing of a profile, or sketch, from one part to another</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Reference-reference’</td>
<td>Sharing of a reference from one part to another</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Revolve’</td>
<td>Use of the revolve feature to create a part [McMahon 1998, Toogood 2006a]</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Sweep’</td>
<td>Use of the sweep feature to create a part [McMahon 1998, Toogood 2006a]</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘Symmetry’</td>
<td>Use of symmetry at a ‘sketcher’ level, e.g. to mirror one half of a sketch to create the whole sketch [Toogood 2006a]</td>
</tr>
<tr>
<td></td>
<td>strategy</td>
<td></td>
</tr>
</tbody>
</table>

Table 35: ‘Sharing’ strategy - ‘Overarching’ and ‘detailed’ approaches

5.2.1 ‘Trial and error’ strategy
The ‘trial and error’ strategy [refer to Chapter Two] would be selected by the learner if they did not have a clear idea of what their product would look like. Although this sounds unlikely, many designers use CAD to experiment with forms at the conceptual development stage of the project [Ulrich & Eppinger 2000, refer to Chapter Two]. This strategy would involve the learner creating a rough model of the design, to enable them
to experiment with different forms. Any product could be created using the ‘trial and error’ strategy if it is unclear what the product is going to look like. Obviously, the learner would need to have a clear understanding of the basic features (‘feature-based’ approach) in order to create the model on CAD. Also, an element of the ‘sharing’ strategy could be used within this strategy to ensure that the parts fit together, although the learner would need to be clear about how many parts there are in their product and how the parts interact with each other.

<table>
<thead>
<tr>
<th><strong>Summary: ‘Trial and error’ strategy</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• The ‘trial and error’ strategy would be used if the learner did not have a clear idea of what the product would look like and involves creating a rough model of the design, to enable the learner to experiment with different forms.</td>
</tr>
</tbody>
</table>

5.2.2 ‘Sharing’ strategy
As shown in Figure 23, the ‘sharing’ strategy would involve elements of all three CAD modelling approaches – the ‘feature-based’ approach, the ‘overarching’ approach and the ‘detailed’ approach. This would allow the learner to look in detail at the individual parts, how they fit together and the relationships between the parts. It is envisaged that this strategy would allow the learner to make design changes to their product easily, as they would have considered how the parts interact with each other. The learner would need to know how many parts there are in the model and whether any of the parts need to share geometry.

‘Overarching’ approach
As established in Chapter Two [section 2.3.2], the ‘overarching’ approach would provide learners with the ‘bigger picture’ when modelling on CAD and includes strategic advice on modelling the product as a whole. Through the previous research, some key strategies emerged relating to the use of ‘overarching’ approaches. It was envisaged that the learner would arrive at an ‘overarching’ approach by answering a set
of key questions, which would provide them with guidelines relating to how to set up and construct their CAD model. The ‘overarching’ approach would help to guide the product designer to use the most effective general CMS for their particular product and is formed of four key strategies (‘duplicate part’ strategy, ‘pattern’ strategy, ‘skeleton’ strategy and the ‘symmetry’ strategy).

- **‘Duplicate part’ strategy (‘overarching’ approach)**

  The ‘duplicate part’ strategy would involve using one part to create a mirror or a copy of another [Toogood 2006a]. Although seemingly obvious, it is important to incorporate this in the CMSS material, as if a learner does not comprehend the simplicity of its application, they may recreate the part from the beginning. There are various advantages to using this strategy, in that a referenced copy can be made from the original part, so that if the original part changes, the new part will update and that it takes very little time to copy or mirror a part. An example of where this strategy might be implemented is when creating alloy wheels for a car, where all four parts can be created from one original part, as can be seen in Figure 24.


Figure 24: Application of the ‘duplicate part’ strategy (‘overarching’ approach) - Alloy wheel example

- **‘Pattern’ strategy (‘overarching’ approach)**

  The ‘pattern’ strategy would involve using the pattern feature to create numerous copies of one feature, or to assemble numerous copies of the same part [Toogood 2006a]. Again, this is a seemingly obvious strategy, but if not

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exploited in the CMSS material, can be overlooked by novice CAD users, who may spend a large amount of time individually assembling components that could have been patterned. Advantages of using this strategy include the saving in time when patterning a feature or part and the ability to exploit the parametric nature of the new part. An example of where this strategy might be used is when assembling buttons on a phone, where all buttons can be assembled at the same time, as can be seen in Figure 25.

![Figure 25: Application of the ‘pattern’ strategy (‘overarching’ approach) - Phone example](http://www.bvrpusa.com/products/ptmobile/captures/images/030.jpg)

- **‘Skeleton’ strategy (‘overarching’ approach)**

  The ‘skeleton’ strategy [Toupin & Benjamin 2002, Brown et al 2001, refer to Chapter Two] would involve the creation of a ‘skeleton model’ containing all of the critical design information, which would be hidden within the main assembly, so that parts within the assembly can be referenced to it and geometry shared from it. The ‘skeleton’ model provides stable references and if the learner is working within a team, it can be stored in an easily accessible location, so that the whole team can access it. There are three aspects that need to be considered before creating a ‘skeleton’ model, which include:

  - How many parts/sub-assemblies the CAD model assembly will contain
  - The naming convention of the parts
  - Their hierarchy within the assembly

---

The advantages of using the ‘skeleton’ model strategy are that the geometry is easily copied between the ‘skeleton’ model and the component and design iterations can be made easily. If modifications are made to the ‘skeleton’ model, the rest of the assembly structure will automatically update. An example of where this strategy might be used is when creating a computer mouse, as can be seen in Figure 26, where the key geometry, such as the cutting line and button profiles, can be incorporated in the ‘skeleton’ model, making the product very easy to update.

![Figure 26: Application of the ‘skeleton’ strategy (‘overarching’ approach) - Mouse example](image)

- ‘Symmetry’ strategy (‘overarching’ approach)
  The ‘symmetry’ strategy (in the context of the ‘overarching’ approach) [refer to Chapter Two] would involve the use of a mirroring operation to ensure that the part is exactly the same on both sides of the mirroring line or plane. However, care needs to be taken to ensure that it would not be more effective to use the revolve tool or the blend tool in some instances. An advantage of using this strategy is that if the original half of the model changed, the second half would also update. An example of where this strategy might be used is when creating a car, where care needs to be taken to ensure that both sides are symmetrical, as can be seen in Figure 27.
Figure 27: Application of the ‘symmetry’ strategy (‘overarching’ approach)
- Car example

‘Detailed’ approach
As noted in Chapter Two [section 2.3.3], the ‘detailed’ approach would provide specific details on how to model effectively on CAD, involving how and where a feature should be used. This would include ensuring that alternate approaches are considered. The ‘detailed’ approach would give the learner ‘detailed’ examples of specific parts and there are several ways that this approach can be communicated, including example exercises and a database of generic products.


- ‘Pattern’ strategy (‘detailed’ approach)
The ‘pattern’ strategy would involve using the pattern feature to create numerous copies of one feature [Toogood 2006a]. An advantage to using the ‘pattern’ strategy is that the features can be parametrically linked, so that if one changed, the remaining instances would also update, which could save the user time. An example of where this strategy might be used is when creating a cheese grater, where several instances of a hole need to be created accurately, as can be seen in Figure 28.
Figure 28: Application of the ‘pattern’ strategy (‘detailed’ approach) - Cheese grater example

- ‘Profile-profile’ strategy (‘detailed’ approach)
  The ‘profile-profile’ strategy would involve using a profile, or sketch, from one part and sharing it so that it can be used in another part. This is particularly useful in parts that have to be modified, because both sketches would update at the same time. An example of where this strategy might be used is when creating the screen for a mobile phone, where the screen shape profile is shared between the upper casing part and the screen itself, as can be seen in Figure 29. This would mean that if the profile of the screen changed, both parts would update automatically.

Figure 29: Application of the ‘profile-profile’ strategy (‘detailed’ approach) - Mobile phone example

10 Image sourced from http://www.worldfood.com/images/greek_tools_cheese_grater.jpg
11 Image sourced from http://www.carphonewarehouse.com/
• ‘Reference-reference’ strategy (‘detailed’ approach)

The ‘reference-reference’ strategy would involve using a reference, such as a datum plane, or reference point, from one part and sharing it so that it can be used in another part. This is particularly useful in parts that have to be modified, because both parts will update at the same time. An example of where this strategy might be used is when creating a hole in a GPS casing, where the reference point needs to be shared between the upper and lower casing part, as can be seen in Figure 30. This would mean that if the reference for the hole changed, both parts would update automatically.

![Figure 30: Application of the ‘reference-reference’ strategy (‘detailed’ approach) – GPS example](http://www.atnet.org/Images/gps1.jpg)

• ‘Revolve’ strategy (‘detailed’ approach)

The ‘revolve’ strategy would involve using the revolve tool in the creation of cylindrical parts. Although seemingly obvious, it was necessary to alert the learner to this tool, so that they would actively consider using it. An example of where this strategy might be implemented is when creating a stool, as can be seen in Figure 31. This would mean that if the design of the stool needed to be changed, the learner could access the profile easily from one sketch.

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‘Sweep’ strategy (‘detailed’ approach)

The ‘sweep’ strategy would involve using the sweep tool in the creation of parts where detail needs to be added to a part using a cross sectional profile. Again, although seemingly obvious, it was necessary to alert the learner to this tool, so that they would actively consider the using it. An example where this strategy might be used is when creating the detail on the face of an iPod, as can be seen in Figure 32. This would mean that if the design of the iPod needed to be changed, the learner could access the cross sectional profile, or trajectory easily.

13 Image sourced from http://www.mickeythompsons tires.com/images/classicII.gif
• **‘Symmetry’ strategy (‘detailed’ approach)**

The ‘symmetry’ strategy (in the context of the ‘detailed’ approach) [refer to Chapter Two] would involve using the symmetry tool to mirror sketches as well as whole features. An example of where this strategy might be used is when creating the base of the lamp, as can be seen in Figure 33, where a dependant mirroring operation could be used within the ‘sketcher’ mode in order to ensure that both sides of the sketch are exactly the same.

![Figure 33: Application of the ‘symmetry’ strategy (‘detailed’ approach) - Lamp example](image)

5.2.3 ‘Separate’ strategy

As noted in Figure 23, the ‘sharing’ strategy would involve elements of the ‘detailed’ approach, as noted previously in section 5.2.3. This would allow the learner to look in detail at the individual parts. It is envisaged that this strategy will allow the learner to make design changes to their parts easily. As noted in Table 36, it is envisaged that the learner would use this strategy if they did not require any parts in their CAD model to link parametrically with other models. The ‘separate’ strategy would involve creating
each of the parts separately and then assembling them together. An example of a product that could be created using the ‘separate’ strategy would be a vase, which is formed of only one part, as can be seen in Figure 34:

![Vase example](http://www.ikea.com/webapp/wcs/stores/servlet/ProductDisplay?catalogId=10103&storeId=7&langId=-20&productId=10118)

**Figure 34: Application of the ‘separate’ strategy - Vase example**

**Summary: ‘Separate’ strategy**

- The ‘separate’ strategy involves elements of the ‘detailed’ approach, which allows the learner to look in detail at the individual parts.

### 5.3 Defining the pre-requisite knowledge of the novice CAD user

It was also necessary to detail the basic knowledge that the learner would need in order to implement the approaches and strategies noted above. The use of all of the basic features and the application of the basic knowledge can also be described as the ‘feature-based’ approach [refer to Chapter Two, section 2.3.1]. As the ‘overarching’ and ‘detailed’ approaches would make use of many of the basic features, it was a prerequisite that the learner understood how to use all of the basic features. This was necessary so that the learner could make an informed decision to create the model using the most effective approach. Therefore, it was assumed that the learner could:

- Use the ‘sketcher’ tool
- Use the blend/loft tool
- Use the copy geometry tools

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• Use the draft tool
• Use the extrude tool (protrusion/cut)
• Use the hole tool
• Use the pattern/array tool
• Use the reference geometry tools
• Use the revolve tool
• Use the round and chamfer feature
• Use the shell feature
• Use the sweep tool

It was envisaged that information relating to recovering from error messages would also be included in the ‘feature-based’ approach.

### Summary: Defining the pre-requisite knowledge of the novice CAD user

| It is a prerequisite that the novice CAD users can use all of the basic features, as noted above, in order to use the CMSS material. |

5.4 Summary

This chapter has been based on a combination of the emergent themes from the Exploratory Study [Chapter Two, section 2.6], prior art and subsequent research in order to define the basic foundations for the content of the CMSS material. The three strategies that the learner can select were defined as below, using a combination of the ‘feature-based’ approach, ‘overarching’ approach or ‘detailed’ approach.

• **‘Trial and error’ strategy** – using the ‘feature-based’ approach to create a rough model of the design, to enable learner to experiment with different forms.

• **‘Sharing’ strategy** – using elements of the ‘feature-based’, ‘overarching’ approach and ‘detailed’ approaches to look in detail at the relationships within and between parts.
• ‘Separate’ strategy – creating parts separately using the ‘feature-based’ approach and, potentially, elements of the ‘detailed’ approach.

It was noted previously [refer to Chapter Two, section 2.6] that the target learner had a number key traits and the next stage was to define clearly the audience, key learning points and constraints for the CMSS material, as can be seen in Table 36.

<table>
<thead>
<tr>
<th>CMSS material</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target audience</strong></td>
<td>• Novice CAD users</td>
</tr>
<tr>
<td></td>
<td>• Limited prior knowledge (basic features)</td>
</tr>
<tr>
<td></td>
<td>• Learners in further/higher education with differing learning styles</td>
</tr>
<tr>
<td><strong>Key learning points</strong> [Chapter Two, section 2.6]</td>
<td>To ensure that:</td>
</tr>
<tr>
<td></td>
<td>• The learner is a competent CAD user</td>
</tr>
<tr>
<td></td>
<td>• The learner can employ effective CMS</td>
</tr>
<tr>
<td></td>
<td>• The learner can create a realistic looking model</td>
</tr>
<tr>
<td></td>
<td>• The learner can make design changes quickly and easily</td>
</tr>
<tr>
<td><strong>Delivery date</strong></td>
<td>• December/January 2004/2005</td>
</tr>
<tr>
<td><strong>Constraints</strong></td>
<td>• Budget</td>
</tr>
<tr>
<td></td>
<td>• Time</td>
</tr>
<tr>
<td></td>
<td>• Resources</td>
</tr>
</tbody>
</table>

**Table 36: Criteria for the CMSS material**

The next stage was therefore to consider how the content could be presented to novice CAD users, considering the elements listed in Table 36.
6 TEACHING AND LEARNING

Overview: This chapter considers approaches to teaching and learning CAD and the implications of the general pedagogy with relation to the CMSS material. A blended learning approach is then examined, leading to a specific blended process incorporating four key communication methods.

6.1 Introduction

It had previously been found that developing material to communicate ‘effective CMS’ was a significant new area of research that potentially presented many benefits to people using CAD within the field of design [refer to Chapter Two]. Key content was discussed in Chapter Five and it was then necessary to consider how to present the material to novice CAD users, as can be seen in the focused research aim in Table 37.

**Focused research aim**

- To generate an accurate description of what should be included in the CMSS material and consider the methods with which to communicate this information effectively to novice CAD users.

**Table 37: Focused research aim from Chapter Two [section 2.7]**

Key criteria for the CMSS material was detailed in Chapter Five [section 5.4]. This stated that the material should address novice CAD users, with limited prior knowledge of using CAD. The ‘limited’ prior knowledge was defined as knowledge and experience of all the basic features [for a full list refer to Chapter Five, section 5.3]. It was also noted that the material should address CAD users within the secondary, further and higher education system, of differing ages and learning styles. These criteria, combined
with the key learning points, delivery date and constraints provide the basis of the information contained within this chapter.

Therefore, the specific research objectives that this chapter examines can be seen in Table 38.

### Specific research objectives - Teaching and learning

- To consider the key approaches to teaching CAD
- To examine the principles of blended learning with a view to providing an engaging medium for all learners
- To describe the process that incorporates this information into the CMSS material

<table>
<thead>
<tr>
<th>Table 38: Specific research objectives - Teaching and learning</th>
</tr>
</thead>
</table>

6.2 Approaches to teaching and learning CAD

There is no one specific approach to teaching and learning CAD, as the approach may vary according to:

a) The type of material (e.g. distance/classroom-based)
b) The context of the material (e.g. to visualise 3D forms/generate an engineering drawing)
c) The teacher
d) The learner

This is highlighted when considering the differences between two approaches that vary due to the type of material, as can be seen in Figure 35. ‘Approach 1’ uses the example of Toogood [2006a] and ‘Approach Two’ uses a typical ‘classroom-based’ approach, as discussed in section 6.2.2.
There are many influencers to selecting an appropriate approach to teaching CAD, primarily because of the immensely subjective nature of teaching and learning as a topic. For example, as well as the ‘type’ of material being designed, the approach that is selected also depends on the personal preferences of the teacher and their teaching style and the preferences of the learner and their learning style. As mentioned previously, the material should address CAD users within the further/higher education system, of differing ages and learning styles. Novice CAD users may therefore fall into one of three educational groups:

- Secondary education user (primarily KS4)
- Further education user
- Higher education user

It was important to consider approaches to teaching and learning from all of these perspectives, in order to apply key pedagogical principles to the CMSS material.

When considering the nature of CAD-based training, it was clear that experience of the CAD system underpinned all training material [refer to Chapter Two, section 2.3.1]. Therefore, the Experiential Learning Theory [Kolb 1984, Kolb et al. 2000] was considered in some depth to ensure that the material followed the basic theoretical principles, as well as appealing to all four basic learning styles [Kolb et al. 2000].
6.2.1 Secondary and further education: Government initiatives

CAD was introduced to the National Curriculum with the launch of ‘The Schools’ CAD/CAM Initiative’ in 1999, for which PTC donated Pro/DESKTOP software to 6,000 schools in the UK [DATA]. The National Curriculum (in particular KS4 level) provided basic information on the subject of how novice CAD users are currently taught. The ‘CAD/CAM in Schools’ website (www.cadinschools.org) describes a ‘Framework of objectives for designing’, which provides rudimentary information relating to how CAD can be used to support the teaching objectives. This can be seen in Table 39 which lists the relevant information relating to teaching 3D CAD, although it is clear that the majority of the points listed in this table relate to teaching the fundamentals of CAD (e.g. use of the basic features) and do not relate specifically to strategic use of CAD.
## Objective: How Pro/DESKTOP CAD software supports this objective:

<table>
<thead>
<tr>
<th>Exploring ideas/the task</th>
<th>How Pro/DESKTOP CAD software supports this objective:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Exploring existing virtual designs</td>
</tr>
<tr>
<td></td>
<td>• Exploring a virtual environment where the new design will exist</td>
</tr>
<tr>
<td></td>
<td>• Explore visual environment by rendering designs</td>
</tr>
<tr>
<td></td>
<td>• Use dimension slider to explore proportions</td>
</tr>
<tr>
<td></td>
<td>• Propose solutions</td>
</tr>
<tr>
<td></td>
<td>• Use alternative modelling methods</td>
</tr>
<tr>
<td></td>
<td>• Save alternative versions</td>
</tr>
<tr>
<td></td>
<td>• Combine components</td>
</tr>
<tr>
<td></td>
<td>• Use palette of 3D shapes</td>
</tr>
<tr>
<td>Developing ideas/modelling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Analyse own ideas</td>
</tr>
<tr>
<td></td>
<td>• Develop alternatives</td>
</tr>
<tr>
<td></td>
<td>• Combine components</td>
</tr>
<tr>
<td></td>
<td>• Use dimension slider to explore changes to proportions etc.</td>
</tr>
<tr>
<td></td>
<td>• Select and allocate appropriate materials</td>
</tr>
<tr>
<td>Planning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Review/modify models to suit manufacture/production</td>
</tr>
<tr>
<td></td>
<td>• Select and match materials to purpose</td>
</tr>
<tr>
<td></td>
<td>• Work as a team/concurrently on the same assembly</td>
</tr>
<tr>
<td></td>
<td>• Output STL and simulate CNC production</td>
</tr>
<tr>
<td></td>
<td>• Estimate quantities of materials for casting etc.</td>
</tr>
<tr>
<td></td>
<td>• Annotate designs in engineering notebook</td>
</tr>
</tbody>
</table>

| Evaluating               |                                                      |
|                          | • Compare virtual outcome against specification      |
|                          | • Evaluate how product benefits user                 |
|                          | • Compare existing products by reverse engineering   |
|                          | • Detect interference between parts                  |
|                          | • Measure mass, volume, surface etc.                 |

Table 39: ‘Framework of objectives for designing’ [www.cadinschools.org: 2006]

The ‘CAD/CAM in Schools’ website [Ibid] also provides interesting, but relatively basic, case studies on approaches used to teach Pro/DESKTOP and considers the teaching strategies as well as pupil outcomes. One case study discusses a project that required the learner to ‘Design an article of furniture which has a primary and a secondary function’ [Ibid:2]. It was clear that the teaching strategies discussed in the case studies listed on the website related to teaching the basics of CAD, as opposed to strategic approaches to learning. However, it was interesting to discover the resources
that had been used within the case studies to teach CAD at a secondary education level, as can be seen in Figure 36.

![Diagram of teaching resources]

**Figure 36: Examples of teaching resources used in case studies [www.cadinschools.org]**

The ‘National Curriculum in Action’ website (www.ncaction.org.uk) and the DATA website (http://web.data.org.uk/data/index.php) also provide relevant information on standards of work at different levels, as well as activities used in teaching, although it was clear that a basic ‘feature-based’ approach generally underpins CAD education at this level.

### Summary: Secondary and further education: Government initiatives

- The National Curriculum provided basic information on the subject of how CAD is currently taught in schools and further education and there exists a substantial amount of guidance related to best-practice teaching. However, a ‘feature-based’ approach generally underpins many methods in teaching CAD today.
6.2.2 Higher education: Empirical evidence

In addition to literature relating to how CAD is currently taught, it was also necessary to collect primary evidence relating to educating novice CAD users. Generally, higher education-based teaching and learning was found to be more flexible than school-based teaching and learning in terms of course design and key learning points. This provided some interesting and useful guidance for the design of the CMSS material.

The lectures\textsuperscript{15} were observed on a weekly basis between October 2002 and July 2003 (one academic year). It was found that the techniques varied between semesters, when the ‘novice’ CAD users had become more advanced, as can be seen in Table 40.

<table>
<thead>
<tr>
<th>Techniques used during Semester One</th>
<th>Techniques used during Semester Two</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hand-outs – click-by-click examples of how to use the basic features</td>
<td>• Hand-outs – click-by-click examples of the more advanced features</td>
</tr>
<tr>
<td>• Lecturing/presentations – to give the student an introduction to the subject. The lectures generally made use of a projector to provide the student a visual reference of Pro/ENGINEER</td>
<td>• Lecturing/presentations – to give the student an introduction to the subject. The lectures generally made use of a projector to provide the student a visual reference of Pro/ENGINEER</td>
</tr>
<tr>
<td>• Simple assignment – in the form of an orthographic engineering drawing</td>
<td>• More advanced assignments – the students were required to design their own product using the features that had been covered during the lectures</td>
</tr>
<tr>
<td>• Visual aides – these were used to illustrate the basic features, such as extrudes, sweeps and revolves</td>
<td>• Website – online help, additional reading</td>
</tr>
<tr>
<td>• Website – online help, additional reading</td>
<td></td>
</tr>
</tbody>
</table>

Table 40: Techniques used in CAD lectures

\textsuperscript{15} The CAD lectures formed part of the Industrial Design and Technology degree at Loughborough University where undergraduates were being taught to use Pro/ENGINEER (PTC) for the first time
It can be seen that many of these tried-and-tested techniques (projector, hand-outs and use of a website) are similar to those being employed in CAD/CAM lessons in schools and are therefore key methods to consider within the CMSS material. It can also be seen that when the CAD user became more advanced, visual aides are not used and instead, more advanced assignments were included.

<table>
<thead>
<tr>
<th>Summary: Higher education: Empirical evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>It was found that many strategies had been used to help to educate novice CAD users. These can be split broadly into three groups:</td>
</tr>
<tr>
<td>o Teaching methods – lectures/presentations</td>
</tr>
<tr>
<td>o Teaching tools – visual aides, hand-outs, website</td>
</tr>
<tr>
<td>o Assessment – assignment</td>
</tr>
</tbody>
</table>

6.2.3 Pedagogy
The National Curriculum describes many examples of ‘good practice’ in teaching CAD. These examples, along with the empirical evidence collated from the CAD lectures, were very useful in discovering how CAD is currently taught, but it was also necessary to consider general theoretical pedagogical issues.

The subject of pedagogy is vast and is covered by many key thinkers such as Archer [1992], Fischer [1991], Keller [1987], Knowles [1984a, 1984b], Kolb [1984] and Kolb et al. [2000] (a useful overview of the key thinkers within the field is provided by Palmer [2001]). A review of literature was carried out to allow the researcher to read broadly around the subject and to identify important elements that were relevant to the research project. From the review of literature, two key aspects were found to be particularly relevant and included:

- Kolb’s ELT [1984, Kolb et al. 2000] - this was seen to be well suited to learning CAD, as it relies heavily on experience.
Visualisation - including visualising the CAD system and the 3D CAD models within the CAD system, as both aspects affect the success of the CAD user. Fischer’s [1991] work was particularly important in terms of visualisation.

The remainder of this section provides an overview of the elements noted above.

**Accelerated learning and adult learning**

The general approach to ‘accelerated learning’ suggests that learners can exceed their original expectation of their ability when taught appropriately and properly motivated [De Porter 2008] and Keller’s ARCS [1987] provided a useful model for motivation. Keller states that there are four key aspects (Attention, Relevance, Confidence and Satisfaction) [Keller 1987] that have to be achieved in order to keep the learner motivated in the material [Ibid:3].

- **Attention** – gaining and sustaining the learner’s attention [Ibid:3]
- **Relevance** – convincing the learner of the relevance of the material [Ibid:3]
- **Confidence** – fostering confidence in the learner [Ibid:3-4]
- **Satisfaction** – help the learner ‘…feel good about their accomplishments’ [Ibid:6]

Keller [1987] provides useful strategies in achieving motivation for the learner, using the ARCS model [refer to 1987:4-5]. It was also important to consider the principles of ‘Andragogy’, in particular using the work of Knowles [1984a, 1984b], Sims & Sims [1995] and Mezirow [2000], as some of the learners could be regarded as adult.

To conform to the principles of ‘Andragogy’, it is important to ensure that the CMSS material clearly explains to the learner why they need to use the material and makes use of a ‘problem-solving’ approach when teaching the subject. It is also be important to provide the learner with immediate feedback [Gagne 1965].
Knowles [1984a] notes that learning is primarily self-directed [1984a:9] and that the adult educator should attempt to promote self-directed and not dependent learners [1984a:9-10]. However, this approach has its limitations and was therefore used with caution as arguably, younger (non-adult) learners need to be directed and may be more dependant.

Knowles [1984a] lists a number of issues that need to be answered when designing training that conforms to the andragogical model [1984a:14-19], which also need to be considered in the design of the CMSS material.

1. **Climate setting.** What procedures would be most likely to produce a climate that is conducive to learning? [Ibid:14]
2. **Involving learners in mutual planning.** What procedures can be used to get the participants to share in the planning? [Ibid:17]
3. **Involving participants in diagnosing their own needs for learning.** What procedures can be used for helping learners responsibly and realistically identify what they need to learn? [Ibid:17]
4. **Involving learners in formulating their learning objectives.** What procedures can be used to help learners translate their diagnosed needs into learning objectives? [Ibid:18]
5. **Involving learners in designing learning plans.** What procedures can be used to help the learners identify resources and devise strategies for using these resources to accomplish their objectives? [Ibid:18]
6. **Helping learners carry out their learning plans.** [Ibid:18]
7. **Involving learners in evaluating their learning.** [Ibid:18]
Summary: Accelerated and adult learning

- The principles of Andragogy were considered within the design of the CMSS material, as a portion of the audience for the CMSS material could be considered to be ‘adult’. It was found to be important for the materials to clearly explain to the learner why they need to use the material and to make use of a ‘problem-solving’ approach. For such an audience, it was necessary to provide the learner with immediate feedback [Gagne 1965].

Experiential Learning Theory

There is a universal agreement, as identified within CAD training material, that in order for the user to learn to use CAD, they have to have experienced it, whether using a click-by-click tutorial, or undertaking an assignment. Archer [1992] believes that humans cannot know anything that they have not experienced through their sense organs and that it is not possible to get a ‘perfect [mental] model’ of something by simply seeing or hearing. It was considered that in order to have a perfect model of how to implement effective CMS, the learner cannot simply watch someone apply these strategies, or listen to someone explaining it – they must actually use the system. Additionally, a key aspect of the theory of ‘Andragogy’ is that adult learners learn ‘experientially’ [TIP theories: 2006]. The ELT [Kolb 1984, Kolb et al. 2000] is therefore well suited to learning CAD, as it relies heavily on transforming experience [Ibid:41]. As Sims & Sims [1995] note, it is especially important to base learning materials on a theoretical foundation, such as Kolb’s [1984] ELT:

   Educators must have more knowledge and understanding of the learning process, particularly how individuals learn. This will help them immensely in both the design and implementation of teaching that enhances learning. If educators relied upon models of how individuals learn, they would be better able to enhance their students’ ability to learn. [Sims & Sims 1995:1]

Kolb et al. [2000] give a comprehensive overview of the ELT, which, they note, is rooted in the work of Dewey, Lewin and Piaget [Ibid:2] and has become ‘…widely
accepted as a useful framework for learning centered educational innovation, including instructional design, curriculum development, and life-long learning’ [2000:22]. Kolb’s ELT [1984, Kolb et al. 2000] cycle comprises of four stages, including ‘Concrete experience’, ‘Reflective observation’, ‘Abstract conceptualisation’ and ‘Active experimentation’, as can be seen in Figure 37. Learners are diverse in the way that they learn, and may rely on different experiences with which to start learning [Ibid]. Kolb et al. [2000] note that there are four key learning styles (‘Accommodating’, ‘Diverging’, ‘Assimilating’ or ‘Converging’) that can be attributed to learner, using the ‘Learning Style Inventory’ [Ibid:4]. The attributed learning style can be based on two stages of the cycle (e.g. ‘Diverging’ can be based on Concrete Experience and Reflective Observation). These four learning styles were useful in identifying key traits of the learners who will be using the CMSS material. The article draws upon a useful overview of the traits of each of the learners who fall within the learning styles above. This can be seen in Table 41.

![Figure 37: ‘Structural Dimensions Underlying the Process of Experiential Learning and the Resulting Basic Knowledge Forms’ [Kolb 1984:42]](image-url)
<table>
<thead>
<tr>
<th>Learning style</th>
<th>Trait of learner</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Diverging’</td>
<td><strong>Learner prefers to:</strong></td>
</tr>
<tr>
<td></td>
<td>• Work in groups</td>
</tr>
<tr>
<td></td>
<td>• Listen with an open mind</td>
</tr>
<tr>
<td></td>
<td>• Receive personal feedback</td>
</tr>
<tr>
<td>‘Assimilating’</td>
<td><strong>Learner prefers:</strong></td>
</tr>
<tr>
<td></td>
<td>• Reading</td>
</tr>
<tr>
<td></td>
<td>• Lectures</td>
</tr>
<tr>
<td></td>
<td>• Exploring analytical models</td>
</tr>
<tr>
<td></td>
<td>• Having time to think through things</td>
</tr>
<tr>
<td>‘Converging’</td>
<td><strong>Learner prefers to:</strong></td>
</tr>
<tr>
<td></td>
<td>• Experiment with new ideas</td>
</tr>
<tr>
<td></td>
<td>• Simulations</td>
</tr>
<tr>
<td></td>
<td>• Laboratory assignments</td>
</tr>
<tr>
<td></td>
<td>• Practical applications</td>
</tr>
<tr>
<td>‘Accommodating’</td>
<td><strong>Learner prefers to:</strong></td>
</tr>
<tr>
<td></td>
<td>• Work with others to get assignments done</td>
</tr>
<tr>
<td></td>
<td>• Set goals</td>
</tr>
<tr>
<td></td>
<td>• Do field work</td>
</tr>
<tr>
<td></td>
<td>• Test out different approaches to completing a project</td>
</tr>
</tbody>
</table>

**Table 41: Traits of learners [Kolb et al. 2000:5-7]**

It should be noted that Kolb’s theory [1984] was refuted by Garner [2008], who does not believe that students can be split into one of Kolb’s [1984] learning styles. Therefore, instead of assigning the CMSS material to one specific learning style, Kolb’s ELT theory should be used to ensure that all learning styles are allowed for within the material. Fedler [1996] suggests that through a mixture of lecturing, explanation, presentation of basic information and methods, practice and exploration of the material, all of Kolb’s learning styles [1984, Kolb et al. 2000] can be allowed for.

The notion of learning through experience and reflection and a key aspect of the theory of ‘experiential learning’ is the constructivist approach, which suggests that the learner should explore the material in order to gain their own knowledge base of the subject. The learner can then use, reflect and build up on the experiences that have been stored within the brain, as opposed to using experiences from the outside world [Sung & Ou
Honebein et al. [1993] summarise the constructivist philosophy and note that ‘Constructivist learning focuses on skills and strategies, rather than facts and rote memorization’ [Ibid:106]. Although there is scope for rote memorization in learning to use CAD, it is believed that the ELT is better suited as an overarching approach to learning to use CAD, as it is grounded in experience. The ELT approach [Kolb Ibid] is therefore ideal in communicating effective CMS to novice CAD users.

Social constructivism, as noted by Pear & Crone-Todd [2001] is also another interesting approach to the ‘experiential learning’ process, which states that the students build up their knowledge from other students through an interaction with them. The students give each other feedback, which Pear & Crone-Todd [Ibid] suggest encourages the learning process and helps them to think of answers they otherwise would not have thought of themselves. They also suggest that the more able students would help the less able students, which would hold advantages for both sets of students and that ‘...the students receive far more substantive feedback than would be possible in a traditionally taught course’ [Ibid:228]. However, this approach could result in learners providing each other with incorrect feedback, although it was considered that the worth of learner-learner interaction [Sabry & Baldwin 2003] was greater than this weakness (especially as the learner could ask for help from an expert user). They suggest that this method of learning is flexible and can be combined with:

- Lectures
- Discussion groups
- Website postings
- Multimedia presentations

Many other learning theories were considered within the initial literature review, in particular, the behaviourist theories. Typically, this theory is based upon a new behavioural pattern being formed by the learner through stimulus-response bonds [Reece & Walker 2003], where they would learn by ‘...receiving a stimulus that provokes a response’ [Ibid:83]. Reece & Walker [2003] claim that ‘...learning is brought about by association between the response and reinforcement’ [Ibid:83].
However, although rote memorization is useful when learning CAD, it was believed that a constructivist approach was more appropriate, as this would involve the learner using, reflecting and building up CAD experiences and CMS knowledge. A constructivist approach is especially important when the CMS task is rather ambiguous, as the learner must think and reflect upon the strategy, rather than simply practice a specific feature.

Also of interest was Honey & Mumford’s Learning Styles Questionnaire [1982], although as the CMSS material was not to be targeted at an individual learner, with an individual learning style, it was decided to instead focus on communication methods that allow for all learning styles (as much as possible), as noted by Kolb [1984, Kolb et al. 2000].

### Summary: Experiential Learning Theory

- Kolb’s ELT [1984, Kolb et al. 2000] was seen to be well suited to learning CAD, as it relies heavily on experience and the four learning styles noted by Kolb [2000] (‘Accommodating’, ‘Diverging’, ‘Assimilating’ and ‘Converging’) were useful in identifying key traits of the learners who will be using the CMSS material.

### Visualisation

Visualisation is a key topic within the context of design, and, as Dahl [2001] notes, ‘...enables the generation, interpretation, and manipulation of information through spatial representation’ [2001:5]. In the context of this research, there are two aspects of visualisation that are particularly important:

- Visualising the CAD system, or ‘complex computer system’ [Fischer 1991]
- Visualising 3D CAD models within the CAD system [Duesbury & O’Neil 1996]
Visualisation of the CAD package is crucial to the success of the learner and is an important consideration in the design of the resource with which to communicate CAD. Fischer [1991] provides a good example of the ‘Levels of system usage’ by a typical user, which emphasises the difference between what learners think exists on a complex computer system and what actually exists in reality, as can be seen in Figure 38.

![Figure 38: Level of system usage](image_url)

This shows how relevant it is to exploit those features that are not classed as ‘basic’ features (e.g. sharing geometry) within the CMSS material, to allow novice CAD users to make a confident and conscious choice to use them. If this is not exploited, although the learner may know that such features exist, they may not feel confident enough to make an informed choice to use them as part of their strategy.

Fischer [1991] lists a number of different methods that can be employed in order to make a complex system comprehensible, which could also be exploited in terms of developing CMS for product designers. These can be seen in Table 42.
How to make a complex system comprehensible [Fischer 1991:17]

How this can be related to the CMSS material

<table>
<thead>
<tr>
<th>Exploit what people already know (e.g., support “human problem-domain communication”),</th>
<th>Exploit the basic features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use familiar representations, based on previous knowledge and analogous to known situations (e.g., take advantage of differential descriptions),</td>
<td>Compare the material to ‘real-life’ objects [Richards 1995, Mahoney 2000]</td>
</tr>
<tr>
<td>Exploit the strengths of human information processing (e.g., the power of our visual system) by putting more information into the world using technology which makes visible what would otherwise be invisible,</td>
<td>Exploit aspects of 3D CAD that would otherwise be difficult to explain without the use of technology [Scanlon et al., 1987, Dwyer 1980]</td>
</tr>
<tr>
<td>Segment information into microworlds (e.g., allow beginners to stay on “main streets”),</td>
<td>Provide different levels of information for the learner to access. For example: Level 1: Overview information Level 2: More detailed information Level 3: In-depth information</td>
</tr>
<tr>
<td>Enhance learning by supporting learning on demand.</td>
<td>Provide instant feedback [Gagne 1965], which also prevents the learner from feeling isolated [Scanlon et al. 1987:264]</td>
</tr>
</tbody>
</table>

Table 42: Making a complex system comprehensible [Fischer 1991:17]

Fischer [1991] provides a good example of the mental models that are generated by three groups of stakeholders using a complex computer system, such as CAD. The first example relates to the models that the designers have of users, tasks and technologies relevant to the design of a system. The second example relates to the models that the users have of the systems and tasks and the final example relates to the models that the systems have of the users and tasks. Essentially, in order to use CAD effectively, the models of the users, tasks, technologies and system should be the same regardless of the stakeholder. However, it should be noted that all stakeholders are individuals and therefore their mental models may not necessarily match exactly. However, the CMSS
material should attempt to ensure that the models from each stakeholder are as comparable as possible.

A key aspect of successfully grasping 3D CAD as a novice user is being able to visualise 3D forms, which is described in depth by Sorby et al. [1998]. CAD itself is a useful visualisation tool, especially when explaining how a 2D profile relates to a 3D form [Duesbury & O’Neil 1996:250, Parkin 2000:pp27-51]. As noted previously, learners are diverse in the way they learn [Kolb 1984, Kolb et al. 2000], so another method in helping learners to visualise forms on CAD is to compare a CAD model to a physical model, providing the learner with a tangible comparable object. This may help the learner to visualise their 3D CAD model, as they can interact with the physical model, view it from multiple view points and relate this to their model on the screen. Richards [1995], agrees with this principle and notes that the use of comparisons of CAD models with ‘real-life’ objects helps students understand and visualise 3D models [refer to Chapter Two]. Mahoney [2000] also concurs and notes that by using physical models as well as CAD models, it is easier for the learners to visualise the 3D model.

<table>
<thead>
<tr>
<th>Summary: Visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Visualisation is a key aspect of 3D CAD education in relation to:</td>
</tr>
<tr>
<td>• Using the CAD system</td>
</tr>
<tr>
<td>• Understanding 3D CAD models</td>
</tr>
<tr>
<td>• Therefore CMSS material should exploit those features that may be outside of the users’ ‘…subset of concepts that the users know and use without problems’ [Fischer 1991:7]. An example of such a feature might be ‘shared geometry’.</td>
</tr>
</tbody>
</table>

6.3 Blended learning: Engaging the learner

Having identified key theories involved in teaching and learning CAD, it was necessary to consider methods and technologies that could be used to apply them. Having noted previously that the material must cater for all learning styles [refer to Chapter Six, section 6.2.3], it was important to use a blended approach to the design of the CMSS
material. The blended learning theory states that in order to create effective learning material, the designer must consider all teaching methods even if they only decide that one is appropriate. However, although this may be relevant for one learner, it is believed that more than one method may be necessary in order to appeal to all learning styles. Gagne [1965] even suggests that on an individual basis, each category of learning (from gaining the learner’s attention right through to enhancing information retention) requires a different method of instruction.

Therefore, combined with the notion that learners are diverse in the way they learn, a number of approaches were found to be relevant for use in the CMSS material. These relate directly to traits of learners as discussed by Kolb [1984, Kolb et al. 2000 – refer to section 6.2.3] and can be seen in Table 43.

In order to allow for people who require ‘quiet time’ to explore the material (who would fall into the ‘Assimilating’ learning style category [Kolb et al. 2000]), it was necessary for all of the material listed above to be available out of teaching time. Also, it was necessary to ensure that support sessions were optional in order to appeal to all learning styles, especially the ‘Diverging’ learning style, who likes to ‘receive personal feedback’ [Kolb 2000].
<table>
<thead>
<tr>
<th>Learning approach used</th>
<th>Associated learning style [Kolb et al. 2000:5-7]</th>
<th>Section in Thesis</th>
</tr>
</thead>
</table>
| Computers (website)    | • ‘Diverging’ (receiving personal feedback)  
• ‘Assimilating’ (reading)  
• ‘Converging’ (experiment with new ideas, simulations, practical applications)  
• ‘Accommodating’ (set goals, field work, test out different approach to completing a project) | 6.3.1            |
| Group work             | • ‘Diverging’ (working in groups, receiving personal feedback)  
• ‘Converging’ (experiment with new ideas, laboratory assignments, practical applications)  
• ‘Accommodating’ (work with others to get assignments done, set goals) | 6.3.2            |
| Print                  | • ‘Diverging’ (working in groups),  
• ‘Assimilating’ (reading, exploring analytical models),  
• ‘Converging’ (experiment with new ideas, simulations, laboratory assignments, practical applications)  
• ‘Accommodating’ (work with others to get assignments done) | 6.3.3            |
| Tutorials              | • ‘Diverging’ (listening with an open mind)  
• ‘Assimilating’ (lectures)  
• ‘Converging’ (simulations)  
• ‘Accommodating’ (set goals) | 6.3.4            |

Table 43: Approaches considered within the CMSS material

6.3.1 CAL: Web-based
The use of computers as a learning aid was considered in great depth in this research, primarily because the target learner had access to a computer, but also because CAL appeals to all of Kolb’s learning styles [Kolb et al. 2000]. This section therefore indicates the strengths and weaknesses of using CAL, as well as highlighting the key points that were considered within the design of the resource.
Historically, computers have been used in an educational context for over fifty years [Allessi & Trollip, 1985:47], and their use within education widely discussed [Graff 2003, Hanafin & Kim 2003, Reisman et al. 2001, Collins et al. 1997]. However, Atkinson [2001] notes that although the development of educational software has been plentiful, its distribution within various parts of education has been restricted. Major developments in computer-based learning tools over the last fifty years are generally influenced by the development of computer technology and teaching pedagogies over these years. There is a plenteous supply of literature on CAL and CAI and much research has been carried out on the subjects of designing learning tools in relation to teaching pedagogies. A good definition of web-based CAL is provided by McKimm et al. [2003]:

**Web based learning is often called online learning or e-learning because it includes online course content. Discussion forums via email, videoconferencing and live lectures (videostreaming) are all possible through the web. Web based courses may also provide static pages such as printed course material.**

*Ibid:*870

A number of advantages and disadvantages of using CAL were noted, which can be seen in Table 44. It should be noted that the following list is not intended to be entirely comprehensive, but instead relates specifically to the CMSS material.
### Advantages of using CAL (web-based)

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantages of using CAL (web-based)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Access to information:</strong> Students can have access to a great deal of information [Scanlon et al. 1987] to provide a vast and varied content</td>
<td><strong>Difficult to understand:</strong> The material may be more difficult to understand if there is not somebody there to explain it [Atkinson 2001]</td>
</tr>
<tr>
<td><strong>Accessibility:</strong> Disabled/blind students can have access to the material, using ‘spoken computer output’ [Scanlon et al. 1987:263]</td>
<td><strong>Expensive to produce:</strong> CAL can be expensive to produce [Scanlon et al. 1987]</td>
</tr>
<tr>
<td><strong>Control the speed:</strong> Learner can control the speed at which they use the resource</td>
<td><strong>Feeling of disorientation, frustration, disaffection:</strong> Learner can feel disorientated, frustrated and disaffected when using CAL [Atkinson 2001:9]</td>
</tr>
<tr>
<td><strong>Individualise learning process:</strong> CAI can individualise the learning process through the use of different media [Stolurow 1968:5]</td>
<td><strong>Feeling of isolation:</strong> Learner may feel isolated [Scanlon et al. 1987:264]</td>
</tr>
<tr>
<td><strong>Linked to LMS:</strong> CAL can be linked to an LMS</td>
<td><strong>Lack of support:</strong> Lack of support for learners who are having problems [Atkinson 2001]</td>
</tr>
<tr>
<td><strong>Potential to communicate:</strong> Pedagogically, computers offer the teacher a vast amount of potential [Thomson 1990:17], in terms of communicating concepts that would be difficult to show in ‘real-life’ [Scanlon et al. 1987, Dwyer 1980].</td>
<td><strong>Presenting the resource ineffectively:</strong> Teachers not presenting the resource effectively due to a lack of training [Atkinson 2001]</td>
</tr>
<tr>
<td><strong>Steer the learning:</strong> It is possible to easily ‘steer’ the student’s learning, as noted by Hoelscher [1986:23].</td>
<td><strong>Pressure on the teacher:</strong> Too much pressure on the teacher to learn to use the tool [Thomas 1990]</td>
</tr>
<tr>
<td><strong>Updatable:</strong> CAL can be easily updated [Scanlon et al. 1987]</td>
<td><strong>Relies on the Internet:</strong> May sometimes rely on access to the Internet</td>
</tr>
</tbody>
</table>

### Table 44: Advantages and disadvantages of using CAL

The greatest potential advantage of the use of CAL is the ability for the material to be updated easily [Scanlon et al. 1987]. The potential for the learner to update the resource as well as the designer, means that a knowledge base can be built. This is a similar idea to the ‘Wiki’ concept [refer to www.wikipedia.org], where an encyclopaedia is
generated from the users of the resource. Another major advantage of the use of CAL is the potential to use various CAL-based media, such as:

- Animations, audio streaming, video streaming
- Downloadable content (e.g. .pdfs, PowerPoints)
- Interactive tutorials, games, simulations
- Links to external sources of information on the Internet
- Podcasts, vodcasts
- Web blogs

With regard to the way that the learner uses the resource, Hoelscher [1986:23] notes that the students’ learning can be steered. This guided approach can allow the designer to dictate the order with which the learner can use the material. However, it should be noted that this approach has its limitations as some learners will not wish to be ‘steered’ and will access the material at their own pace and in their own order. A sound method of structuring the material to allow all learners to access the overview information at the very least is to use three different levels of knowledge within the resource. For example, level 1 - overview information, level 2 - more detailed information and level 3 - in-depth information [refer to Table 42 ‘Making a complex system comprehensible’ Fischer 1991:17]. A key advantage of CAL is that the learner can control the speed at which they undertake their learning. In a wider commercial context, CAL can be linked to an LMS, whereby the CAD users’ learning can be guided, tracked and improved.

Another key advantage is the notion of computers allowing the teacher to communicate concepts that would be difficult to show in ‘real-life’ [Scanlon et al. 1987, Dwyer 1980], which is particularly relevant for teaching CAD, as a computer allows the teacher to demonstrate how a CNC machine works, or provide an animation showing a product ‘exploding’. A generic advantage of CAL is that the material can conform to standards for accessibility and allow disabled students to use the material [Scanlon et al. 1987:263]. This can be implemented by using more than one method to describe an aspect of the material, e.g. an image.
Montelpare & Williams [2000] list some additional advantages of using the Internet pedagogically, as can be seen in Figure 39.

<table>
<thead>
<tr>
<th>Useful and relevant (up-to-date)</th>
<th>Effective way of presenting material</th>
</tr>
</thead>
<tbody>
<tr>
<td>[gained] familiarity with technology</td>
<td>[gained] confidence from hands-on experience</td>
</tr>
<tr>
<td>Provided knowledge &amp; experience</td>
<td>[Course was] challenging</td>
</tr>
<tr>
<td>Information transfer to other courses</td>
<td>Useful for future possibilities</td>
</tr>
<tr>
<td>Ability to access software &amp; computer from home</td>
<td>Introduced to powerful software</td>
</tr>
<tr>
<td>E-mail was an easy option to contact the professor</td>
<td>Appreciated the self-directed learning approach</td>
</tr>
<tr>
<td>The approach encouraged interactive teamwork</td>
<td>Increased computer literacy [in a general sense]</td>
</tr>
</tbody>
</table>

**Figure 39: Noted advantages to including the Internet in the Curriculum**

[Montelpare & Williams 2000:92]

An obvious weakness of the use of web-based CAL material is that it relies on educational institutions and the learner to have access to the Internet. Another disadvantage is that the learner may feel isolated [Scanlon et al. 1987:264], as well disorientated, frustrated and disaffected [Atkinson 2001:9]. Atkinson [2001] also notes that the material may be more difficult to understand if there is not somebody there to explain it and that there is a lack of support for learners who are having problems. However, this is easily overcome by providing contact details for users having problems. Another difficulty with CAL relates to the teacher, as opposed to the learner. For example, if the teacher has not had sufficient training, they may not present the resource effectively [Atkinson 2001] and that the teacher may feel under too much pressure to learn to use the tool [Thomas 1990]. CAL material can also be expensive to produce, especially with relation to compatibility across different Internet platforms.

However, it is believed that when applying CAL (web-based) in the context of this research, the disadvantages noted above were overcome in the following ways:

- Providing Internet access to the learner. The Internet is available within almost all secondary, further and higher educational institutions and where this is not the case, it may be possible to provide the learner with a CD-ROM version (with slightly limited functionality).
• Providing instant feedback to the learner [Scanlon et al. 1987:264], to ensure that the learner does not feel isolated. This could be provided through the use of discussion forums or by providing a service whereby the learner can email for help, where help would be provided within a certain amount of time. Again, if the learner felt disorientated, frustrated and disaffected, they could attend tutorials, as noted in section 6.3.4.

• Providing tutorials, to ensure that the learner has the opportunity to resolve any difficulties.

• Ensuring that the ‘teacher’ has adequate prior training.

• Ensuring that funding is in place to develop the CAL material.

Approaches to designing CAL material have been discussed widely and there are several principles that should be followed. McKimm et al. [2003] present a useful diagram concerning the planning of a web-based course, which could be used as a constant evaluation method throughout the design of the resource, as can be seen in Figure 40.

![Figure 40: The learning cycle [McKimm et al. 2003:871]](image)

The aspects listed by McKimm et al. [Ibid] have been covered within the thesis as per Table 45.
Table 45: Aspects of the learning cycle [McKimm et al. 2003:871]

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of curriculum</td>
<td>Chapter Seven: Pilot Study Two</td>
</tr>
<tr>
<td></td>
<td>Chapter Eight: Final CMSS material</td>
</tr>
<tr>
<td>Pedagogy</td>
<td>Chapter Seven: Pilot Study Two</td>
</tr>
<tr>
<td></td>
<td>Chapter Nine: Main Study and Results</td>
</tr>
<tr>
<td>Assessment</td>
<td>Chapter Nine: Main Study and Results</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Chapter Nine: Main Study and Results</td>
</tr>
<tr>
<td>Feedback and modification to curriculum</td>
<td>Chapter Ten: Discussion</td>
</tr>
<tr>
<td></td>
<td>Chapter Eleven: Conclusion and future directions for research</td>
</tr>
</tbody>
</table>

The basic principles discussed by Allessi & Trollip [1985] provide a useful background to designing computerised tutorials, in particular the layout of the text, colour, prompts, feedback and the use of graphics and animations. Allessi & Trollip [1985] also discuss four activities that should be carried out with regard to successful instruction using a computer, including presenting the information, guiding the student through the information, allowing the student to practice the skills and then assessing the learning.

Magoulas et al. [2003] suggest that learning styles are an important variable with regard to how students learn as factors such as ‘... gender, age group, prior experience’ [Ibid:511]. In order to create a truly individualised learning experience, they suggest that several aspects need to be considered, as can be seen in Figure 41.
It can be seen that although the goals, knowledge and background of the learners may be similar, in order to create a student model that incorporates individual differences, the learners’ preferences and learning styles have to be considered. Although it is not possible to provide a completely individualised learning experience within the scope of this research, it may prove to be interesting further work.

Sabry & Baldwin [2003] discuss three types of learning interaction – learner-learner, learner-tutor and learner-information [Ibid:444]. This is similar to Chou’s [2003] notion of different groupings for the various ‘functions’, which were evaluated by experienced designers of web-based learning systems (learner-interface, learner-content, learner-instructor and learner-learner). Sabry & Baldwin’s [2003] visual interpretation of their categories for web-based learning interaction can be seen in Figure 42. This represents how the learner gathers information that is presented to them through various different forms of media (learner-information), interacts with the tutor (learner-tutor) and interact with other learners (learner-learner) [2003:444–445]. It is clear that providing learner-learner interaction and learner-tutor interaction is a useful way to overcome the feeling of isolation by the learner.
With regard to structuring the content of a resource, Montelpare & Williams [2000] discuss the hierarchy of learning, which suggests that the learner moves through different phases of learning until they reach ‘wisdom’, as be seen in Figure 43.

As can be seen, the learner starts their learning journey with evidence taken from separate facts, such as text, video and graphics. This is then combined to form information, which is put into context and understood to form knowledge. Or, as Montelpare & Williams [2000], suggest ‘...knowledge represents that point at which the
learner gives specific meaning to the information’ [Ibid:88]. The student will then reach the wisdom stage where they achieve an action in relation to the knowledge.

### Summary: CAL (web-based)

| The main advantage of using CAL is that it appeals to all four of Kolb’s [1984, Kolb et al. 2000] learning styles. |

#### 6.3.2 Group work

Group work was considered to be necessary to provide a blended approach to the CMSS material and to appeal specifically to the ‘Diverging’ and ‘Accommodating’ learning styles [Kolb et al. 2000]. Group work was seen to be a useful way to introduce a topic, where learners can work together through an exercise and provide learner-learner interaction [Sabry & Baldwin 2003]. There are many advantages and disadvantages of using group work, as can be seen in Table 46:

<table>
<thead>
<tr>
<th>Advantages of group work</th>
<th>Disadvantages of group work</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Learner-learner interaction:</strong> Provides the opportunity for learner-learner interaction [Sabry &amp; Baldwin 2003], conforms to social constructivist theories [Pear &amp; Crone-Todd 2001]</td>
<td><strong>Can be difficult to control:</strong> For example, if the learners talk amongst themselves</td>
</tr>
<tr>
<td><strong>Teamwork:</strong> Develops teamwork [Rhee &amp; Walker 2003:131]</td>
<td><strong>Uneven sharing of workload:</strong> Workload could be shared unevenly, if one learner does the majority of the work</td>
</tr>
</tbody>
</table>

#### Table 46: Advantages and disadvantages of group work

A clear advantage of group work is that it provides the opportunity for learner-learner interaction [Sabry & Baldwin 2003], where the learners can resolve problems between themselves. Another more generic advantage, is that the learner has the opportunity to
develop team working skills. Disadvantages of group work are that the workload may be shared unfairly, especially when considering computer work and the less-active learner may not have an enriched learning experience. Another disadvantage is that with larger groups, the session could be come difficult to control.

However, it is believed that when applying group work in the context of this research, the disadvantages noted above can be overcome, in the following ways:

- The ‘teacher’ should check each group individually to ensure that the learner stays on track with their learning objectives
- The ‘teacher’ should monitor the group work, to ensure that the learning is shared equally between the group

### Summary: Group work

- It was necessary to include group work to appeal specifically to the ‘Diverging’ and ‘Accommodating’ learning styles [Kolb et al. 2000].

#### 6.3.3 Print

Print was considered to be a small but necessary part of the blended learning media, to appeal particularly to the ‘Assimilating’ learning style [Kolb et al. 2000]. The use of print is also a means with which to communicate assignments and click-by-click exercises for those who prefer to view the material on paper, rather than on the screen. It acts as a very useful introduction for information relating to other media, for example, web-based material, by providing the learner with the necessary details with which to access the material.
Advantages of print | Disadvantages of print
---|---
• Remote access to material: Printed materials can be accessed ‘on the move’ | • Expensive: Can be expensive to produce
• Suits specific learning style: The use of printed materials provides a good optional source of information for those learners who prefer to use print to other types of media | • Out-of-date: The printed material can quickly become out-of-date and irrelevant

Table 47: Advantages and disadvantages of using printed materials

A clear advantage of print, as can be seen in Table 47, is that it can be accessed almost anywhere, for example, when in transit, and that it provides an optional source of information for those learners who prefer to use print to other types of media.

Disadvantages of print are that it can easily become out-of-date and can be difficult to update. Another disadvantage is that print can be expensive to produce, for example, when considering artworking, printing and distribution costs.

However, it is believed that when applying print in the context of this research, the disadvantages noted above can be overcome, in the following ways:

- By periodically revising the printed materials, it will ensure that the content does not become out-of-date.
- By ensuring that the print element is only a minor aspect of the CMSS material, it will help to keep costs to a minimum.

Summary: Print

- It was necessary to include print specifically to appeal to the ‘Assimilating’ learning style [Kolb et al. 2000].
6.3.4 Tutorials

A ‘tutorial’, as Reece & Walker [2003:36] note is an ‘Interaction between the teacher and one or a small group of students providing opportunity for guidance and support’ [Ibid:36], which requires a ‘high’ level of participation from the learner [Ibid:108]. Tutorials appeal to all learning styles, as shown previously in Table 43.

Reece & Walker [2003:136-137] note that during the tutorial, the teacher sets the learner a task and the learner uses the tutorial to prepare for the task. This method may therefore be an effective means with which to introduce the subject of CMS to the novice CAD users. It emerged in Chapter Four [section 4.4], that by providing the learners with support when modelling on CAD, it may be possible to resolve the problems they have with a particular feature, to allow them to use it confidently in the future. Tutorials may therefore be an effective way to provide support to the CAD users and a number of advantages and disadvantages of using tutorials can be seen in Table 48.

The fact that learners will receive individual attention during a tutorial [Reece & Walker 2003:137] helps to ensure that the learner does not feel isolated and can also interact with other learners. Another advantage, from the teacher’s standpoint, is that the learning can be adapted by the teacher immediately, if they feel that it is pitched too high or too low, or if they feel that a particular method is not working for them. By experiencing the learning first hand, it is possible for the teacher to see if progress is being made and to judge the quality of the learning [Reece & Walker 2003:137]. The teacher can also make use of a variety of different media, such as showing videos and using visual aides. Reece & Walker [2003:137] also note that the teacher can offer valuable support for the learner to progress [Ibid] and also has the opportunity to establish a rapport with the learners [Ibid].
Advantages of tutorials | Disadvantages of tutorials
--- | ---
- **Easily adaptable:** Learning can be adapted immediately | - **Expensive:** Costly because of one-to-one relationship [Reece & Walker 2003:137]
- **Learner is not isolated:** Learner does not feel isolated [Scanlon et al. 1987:264] | - **Location:** Finding a suitable room [Reece & Walker 2003:137]
- **Personal:** Learner receives individual attention [Reece & Walker 2003:137] and individual concerns are addressed [Ibid:137] | - **Pace:** Learning happens at teacher’s pace
- **Progress:** Valuable support to progress [Reece & Walker 2003:137] | - **Presentation skills:** Teachers may not present effectively due to lack of training
- **Quality of learning can be judged:** Tutorials provide an opportunity to see the quality of learning [Reece & Walker 2003:137] | - **Pressure:** Student may feel pressurised [Reece & Walker 2003:137]
- **Rapport:** Opportunity to establish a rapport with students and improve communication [Reece & Walker 2003:137] | |
- **Resources:** Teacher can make use of a variety of media | |

Table 48: Advantages and disadvantages of using tutorials

Disadvantages of tutorials from the point of view of the learner include the fact that they may feel pressurised [Reece & Walker 2003:137] and that the learning may happen at the pace of the teacher, not the learner (if there is more than one learner). Disadvantages from the stand point of the teacher include the fact that if there is only one learner, the cost of a tutorial may be expensive [Reece & Walker 2003:137]. Also, the teacher may not present the material effectively due to lack of training, which could hinder the learning process. Reece & Walker [Ibid] also note that the logistical issue of finding a suitable room is also a disadvantage of tutorials.
However, it is believed that when holding a tutorial in the context of this research, the disadvantages noted above can be overcome in the following ways:

- Conducting the tutorial in an informal style to ensure that the learner does not feel pressurised
- Continually monitoring the learner’s progress during the tutorial, to ensure that the pace is appropriate
- Ensuring that there is more than one learner in each group to ensure that the session is cost effective with regard to the one-to-one time with the tutor
- Ensuring that the ‘teacher’ has adequate prior training
- Ensuring that a suitable room is available in advance of the tutorial

### Summary: Tutorials

| Tutorials appeal to all learning styles [Kolb et al. 2000] and were therefore considered an effective way with which to introduce the subject of CMS to the novice CAD users. |

### 6.3.5 Technologies disregarded

A number of other technologies were also considered, but not used within the research, including the use of audio, CD-ROM, DVD/videos and VR, as can be seen in Table 49.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Rationale for discarding the approach</th>
</tr>
</thead>
</table>
| Audio CD/cassette        | **Key advantage:**  
|                          | • It is possible for the learner to easily control the speed at which the material is delivered  
|                          | **Reasons for not using audio CD/cassettes:**  
|                          | • Audio CDs/cassettes are entirely non-visual when used independently and provide a non-immersive learning environment. It may therefore be difficult to sustain the learners’ attention  
|                          | • The audio could be expensive to produce and difficult to update  
|                          | • It could be difficult to monitor learners’ progress                                                                                                                                 |
| CD-ROM                   | **Key advantage:**  
|                          | • Does not rely on learners having access to the Internet  
|                          | **Reasons for not using CD-ROM:**  
|                          | • No facility to provide learner-learner interaction [Chou 2003]  
|                          | • Time consuming and costly to update and re-supply to learners                                                                                                                                 |
| DVD/video                | **Key advantage:**  
|                          | • It is possible for the learner to easily control the speed at which the material is delivered  
|                          | **Reasons for not using DVD/video:**  
|                          | • It could be expensive to produce  
|                          | • It could be difficult to monitor learners’ progress  
|                          | • Relies on learner having DVD/video player                                                                                                                                 |
| Use of VR to create a    | **Key advantage:**  
| virtual classroom        | • If the learner had access to the necessary equipment at home, they would not need to physically visit the educational establishment to access the classroom training  
|                          | **Reasons for not using VR:**  
|                          | • Costly to produce due to the complexity of the VR programmes/equipment  
|                          | • It is unlikely that the learner would have VR equipment in their own home                                                                                                                                 |

Table 49: Technology not used
Summary: Technologies disregarded

- Four key technologies (Audio CD/cassette, CD-ROM, DVD/video and VR) were considered, but not used.

6.4 Blended process
The final stage was to finalise a process with which to incorporate the information discussed within this chapter into the CMSS material. As discussed previously, the blended process involved the four elements shown in Figure 44.

![Blended process diagram](image)

Figure 44: Blended process

The next stage was to consider how these blended elements could be utilised, as can be seen in Figure 45.
Figure 45: Utilization of blended elements

Scanlon et al. [1987:274-276] note eight key points to consider when using CAL, which have been considered in the design of the CMSS material, as can be seen in Table 50.
Points to consider when using CAL

<table>
<thead>
<tr>
<th>How point has been considered within the CMSS material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational justification</td>
</tr>
<tr>
<td>• Refer to Chapter Two</td>
</tr>
<tr>
<td>Resources required</td>
</tr>
<tr>
<td>• Computers (with Internet access)</td>
</tr>
<tr>
<td>• Projectors (tutorials)</td>
</tr>
<tr>
<td>• Handouts</td>
</tr>
<tr>
<td>Timing and place of use</td>
</tr>
<tr>
<td>• December 2004 - January 2005</td>
</tr>
<tr>
<td>Assessment</td>
</tr>
<tr>
<td>• Evaluation sessions December 2004 - June 2005</td>
</tr>
<tr>
<td>Support and documentation</td>
</tr>
<tr>
<td>• Additional hand-outs</td>
</tr>
<tr>
<td>Briefing the tutors</td>
</tr>
<tr>
<td>• N/A – sessions to be implemented by the researcher</td>
</tr>
<tr>
<td>Monitoring and evaluating</td>
</tr>
<tr>
<td>• Support sessions</td>
</tr>
<tr>
<td>Liaising with the programmers</td>
</tr>
<tr>
<td>• To be held on a weekly basis</td>
</tr>
</tbody>
</table>

Table 50: Eight key issues to consider when using CAL [Scanlon et al. 1987:246-276]

Summary: Blended process

- A blended process has been described, that incorporates a number of communication approaches.
- The communication approaches to be used in the delivery of the CMSS material are:
  - Computers (website)
  - Group work
  - Print
  - Tutorials
6.5 Summary
At the outset of the chapter, some specific research objectives were described [Table 38], relating to achieving the focused research aim [Table 37], which are discussed below, with a particular focus on implementing the learnings into the CMSS material.

Consider the key approaches to teaching CAD
The National Curriculum provided basic information on key approaches to learning CAD (from the perspective of the teacher), in respect to schools and further education. It was clear that a large amount of information was available relating to best-practice in teaching novice CAD users to create and develop CAD models. It was found that resources such as websites, text books, worksheets and projectors are currently used to fulfil the National Curriculum requirements for CAD education. It was also obvious that a ‘basic’ approach generally underpins many methods that learners are being taught. In higher education, a variety of teaching strategies were used, such as teaching methods (lectures/presentations), teaching tools (visual aides, hand-outs, website) and assessment (assignment).

With regard to target audience of the CMSS material, it was necessary to consider Accelerated learning and adult learning [De Porter 2008, Keller 1987, Knowles 1984a, Knowles 1984b, Mezirow 2000] in some depth. It was found to be important to clearly explain to the learner why they needed to use the material and to make use of a ‘problem-solving’ approach.

Kolb’s [1984, Kolb et al. 2000] ELT was found to be well suited to learning CAD, as it relies heavily on experience. The four learning styles noted by Kolb et al. in 2000 (‘Accommodating’, ‘Diverging’, ‘Assimilating’ and ‘Converging’) were useful in identifying key traits of the learners who will be using the CMSS material. From this, it was possible to identify a variety of different communication methods and strategies that should be used in the CMSS material.

Visualisation is a key aspect of 3D CAD education from a novice CAD users’ standpoint in relation to using the CAD system and understanding 3D CAD models.
Fischer’s [1991] work on making complex computer systems comprehensible was therefore very important. In terms of helping the learners to understand 3D CAD models, Richards [1995] and Mahoney [2000] note that comparing the CAD model to ‘real-life’ objects can be a useful visualisation tool [refer to Chapter Two].

To summarise, approaches to teaching CAD vary tremendously depending on the type of material, the teacher and the learner. However, by having a clear idea of the target audience and the nature of the material being taught, it was possible to consider specific and relevant pedagogical approaches to be applied to the CMSS material.

**Examine the principles of blended learning with a view to providing an engaging medium for all learners**

Having considered the four learning styles noted by Kolb [1984, Kolb et al. 2000], it was possible to establish a number of engaging communication methods to ensure that the material allowed for all learning styles (‘Accommodating’, ‘Diverging’, ‘Assimilating’ and ‘Converging’ [Kolb Ibid]). Tutorials were considered appropriate, as they appeal to all four learning styles. Printed material appeals specifically to the ‘Assimilating’ learning style [Kolb et al. 2000] and was therefore seen to be a necessary medium with which to introduce the subject of CMS to the novice CAD users. CAL (web-based) holds a vast amount of potential for the CMSS material, especially as it is accessible to disabled learners and appeals to all four learning styles [Kolb Ibid]. The potential to link the material to an LMS is also another obvious advantage over other media. As the CAL forms the greatest part of the CMSS material, it was important to consider general principles involved in the design of the resource, especially from key thinkers such as McKimm et al. [2003] and Sabry & Baldwin [2003]. Group work was also seen to be a necessary aspect of the material and appeals specifically to the ‘Diverging’ and ‘Accommodating’ learning styles [Kolb Ibid]. Other technologies were considered and later dismissed, including Audio CD/cassette, CD-ROM, DVD/video and VR.

It is believed that the four communication methods selected for use in the CMSS material will provide an engaging medium for the target audience.
Describe the process that incorporates this information into the CMSS material

A blended process has been described, that incorporates a number of communication approaches. The communication approaches to be used in the delivery of the CMSS material are:

- Computers (website)
- Group work
- Print
- Tutorials

Having selected the medium with which to present the resource, it was necessary to ensure that the material was relevant and exciting to its target audience. This is addressed in Chapter Eight, which considers the design of the course material, from the colours chosen [Boyle 2001, Whelan 1994, Itten 1973], to the way the material is presented. When the learner first uses the resource, there is no dispute that it should be simple enough for all learners to work through, ensuring no one learner is discouraged by the material being too challenging. Richards [1995] believes that a great deal can be accomplished pedagogically by using simple forms within exercises [Ibid:3].

Therefore, the next stage was to consider whether it was possible to communicate effective CMS to novice CAD users.
7 PILOT STUDY TWO

Overview: This chapter provides an overview of the CMSS material that has been tested using Pro/DESKTOP and the implications for the design of the final version of the CMSS material.

7.1 Introduction
Previous research suggested that there were three key CAD modelling approaches [refer to Chapter Two], which were explored in detail in Chapter Five. It was also found that there were eight factors that influenced the strategy that was chosen to model a part on CAD, which essentially related to the participants feeling ‘forced’ to select a certain CMS in some situations [refer to Chapter Four, section 4.4]. Solutions were considered that attempted to negate each point, which bear an impact on the design of the CMSS material. Therefore, this information, combined with the review of literature concerning teaching and learning [refer to Chapter Six], was used to design and trial a number of different iterations of the CMSS material. The focused research aim, taken from Chapter Two [refer to section 2.7], can be seen in Table 51.

<table>
<thead>
<tr>
<th>Focused research aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>To generate an accurate description of what should be included in the CMSS material and consider the methods with which to communicate this information effectively to novice CAD users.</td>
</tr>
</tbody>
</table>

Table 51: Focused research aim from Chapter Two [section 2.7]
A specific research objective was then generated, as can be seen in Table 52:

<table>
<thead>
<tr>
<th>Specific research objective: Pilot Study Two</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To generate feedback about the CMSS material from a range of CAD users</td>
</tr>
</tbody>
</table>

**Table 52: Specific research objective - Pilot Study Two**

A number of draft iterations of the CMSS material were created, which were tested over the course of one year. A convenience, theoretical sampling strategy was used to select the participants within this part of the research. Access was available, through Loughborough University, to a considerable number of Pro/DESKTOP users of varying abilities. As the CMSS material was envisaged to be non-software specific, it was decided to use participants who were learning to use Pro/DESKTOP, as well as those who were learning to use Pro/ENGINEER.

It was necessary to generate several iterations of the content to ensure that key messages were put across successfully to the target audience. The final version of the CMSS material (discussed in Chapter Eight) was developed through feedback from the participants who used the material within an educational context between 2003 and 2004.

### 7.2 Overview of the CMSS material

It was noted previously that the blended process used to communicate CMS should incorporate the use of:

- Computers (website)
- Group work
- Print
- Tutorials
Therefore, Table 53 shows how the aspects listed above have been tested within this study:

<table>
<thead>
<tr>
<th>Blended process</th>
<th>7.3 Iteration 1: CAD/CAM achiever</th>
<th>7.4 Iteration 2: August 2003</th>
<th>7.5 Iteration 3: June 2004</th>
<th>7.6 Iteration 4: August 2004</th>
<th>7.7 Iteration 5: July 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computers</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group work</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Print</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Tutorial</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 53: Testing aspects of the blended process

It was necessary to evaluate the content of the material, as well as the delivery method [McKimm et al. 2003], before embarking on the main PhD trial. The following points were taken into account throughout the prototype versions of the CMSS material, to ensure that wherever possible, the novice CAD user would not feel ‘forced’ to select a specific CMS [refer to Chapter Four, section 4.4]:

- Wherever possible, participants were provided with one-to-one support when modelling on CAD
- Parallels were drawn between the product being modelled on CAD and the tangible ‘real-life’ object
- Learners were shown the potential to exploit the CAD model (e.g. to create engineering drawings and renderings)
- Wherever possible, learners were provided with a formal planning process to construct their CAD model
- Where relevant, learners were shown how to make use of shared geometry
- Wherever possible, learners were given clear examples of how to use those features that were perceived as more ‘complicated’
Wherever possible, learners were shown how to recover from error messages (although this was envisaged to form part of the ‘feature-based’ approach)

Wherever possible, learners were shown the time implications of using an ineffective method to model on CAD and the benefits of using an effective method

All participants were provided with the same CMS input to ensure that if a team modelling situation occurred, the team could model to the same ‘level’

7.3 Iteration 1: ‘CAD/CAM achiever’ material

The first iteration of the CMSS material was used within the ‘CAD/CAM Achiever’, which was presented as a CD-ROM-based CAD learning resource. This was trialled during 2003 and provided a guided approach to learning to use Pro/DESKTOP. The target audience was secondary education CAD users and the client was Denford Limited. Figure 46 shows a screen print of the resource, which contained an early version of the CMS content. This involved:

- An introduction to the subject of CMS, including an ‘incentive’ tutorial [Toogood & Zecher 2006], drawing parallels to ‘real-life objects’ [Richards 1995, Mahoney 2000]
- A CMS section, including the use of ‘overarching’ approaches [refer to Chapter Two, section 2.3.2 and Chapter Five, section 5.2.2] and ‘detailed’ approaches [refer to Chapter Two, section 2.3.3 and Chapter Five, section 5.2.2], as well as a tyre example exercise [refer to Chapter Two, section 2.2]
- An overview of all of the basic features in Pro/DESKTOP [refer to Chapter Two, section 2.3.1 and Chapter Five, section 5.3]
7.3.1 Introduction and incentive tutorial

Aside from the main incentive to learn the CAD package, novice CAD users may benefit from tutorials that incentivise their learning experience. Incentive tutorials provide the learner with a ‘goal’ or a ‘motivation’ to learn the package by showing them what they will be able to achieve if they complete all aspects of the tutorial. Toogood & Zecher [2006] provide an ‘incentive’ tutorial, whereby learners are given an overview of the capability of the software [Ibid] in order to ‘...help users keep aware of the big picture even when they are deeply involved in the detailed inner workings later’ [Ibid:ii]. Another example of an ‘incentive’ aspect is think3’s training resource ‘Monkey Wrench Conspiracy’, presented in the form of a video-game [Schmitz 1999]. In order to play the game, the learner must design products using CAD in order to proceed through the scenario. The incentive aspect of this is the need to continue the game, whilst learning to use CAD in order to proceed. The game helps to show the learner that 3D CAD is not as intimidating as they may have first thought [Ibid]. Alias StudioTools™ ‘Art to Part’ resource provides an ‘incentive’ aspect through the use of various tutorials, which together allow the learner to fully model, render and rapid prototype a product using Alias StudioTools™. A strength of this approach is that the learner is introduced to the software by modelling, rendering and rapid prototyping a typical ‘designerly’ product, as opposed to creating singular engineering-based parts.
(e.g. a caster from a chair or a locking mechanism). Therefore, part of the introduction to the material included an incentive tutorial, using the example of a toy Land Rover Freelander, as can be seen in Figure 47. The tutorial showed the learner how to assemble a seemingly complicated CAD model and render the model using colours and materials of their choice. The aim was to give the learner an overview of the capabilities of the CAD package, as well as providing an incentive to learn to use the material.

Figure 47: CAD/CAM Achiever - Incentive tutorial

It was found to be necessary to draw parallels between ‘real-life objects’ [refer to Chapter Four, section 4.4, Richards 1995, Mahoney 2000], which was part of the rationale for choosing the toy Land Rover Freelander (as this only contained three simple parts for the learner to assemble [refer to Figure 48] and looked impressive when assembled). This exercise also made it possible to draw parallels to ‘real-life’ CAD activity, by relating the assembly of the model in ‘real-life’ to assembling the model on CAD, which supports Kolb’s ELT [1984, Kolb et al. 2000].
7.3.2 CMS section

As noted previously, the research is focused on Product Designers who would use the ‘sharing’ strategy [refer to Chapter Five, section 5.2.2]. It was therefore necessary to ask the learners two basic questions, in order to guide those who were not using this approach to an alternate approach (e.g. ‘trial and error’ strategy or ‘separate’ strategy):

- ‘Is the part symmetrical?’
- ‘Can any of the parts share the same geometry?’

Therefore, if the learner answered ‘yes’ to either of the questions, they were advised to use the ‘sharing’ strategy, which included the following ‘overarching’ approaches:

- The ‘duplicate part’ strategy [refer to Chapter Five, section 5.2.2] – the learner would use one part to create another part
- The ‘pattern’ strategy [refer to Chapter Five, section 5.2.2] – the learner would make use of the ‘array’ tool to duplicate key features or parts

16 It should be noted that the ‘skeleton’ strategy [refer to section 5.2.3] was not used within this version of the material as the software and learner were not considered advanced enough to benefit from the strategy
• The ‘symmetry’ strategy [refer to Chapter Five, section 5.2.2] – the learner would use a mirroring operation to ensure that the part is symmetrical (within sketcher or when the part had been completed)

The learner was then prompted to move on to the ‘detailed’ approach section, which provided them with a more specific strategy to consider when creating the separate parts. As this material was a relatively early iteration of the CMSS material, a fairly primitive approach was used to guide the learner into using the correct feature/tool to model with. In this example, four groups of similar products were displayed, that were typical of being modelled using the extrude tool, sweep tool, loft tool or revolve tool [refer to Figure 49]. The learner was asked to look at the four groups and was asked to indicate which group of models was most similar to the model that they needed to create. When they had chosen one of the groups, they were asked to model their part using either extrusions, revolves, lofts or sweeps.

![Figure 49: CAD/CAM Achiever - Groups of models that can be created using similar tools (A = extrude tool, B = loft tool, C = revolve tool, D = blend tool)](image)

An example exercise was then provided in order to show the learner why it is important to consider which CMS they use. The learner was asked to look at a rendering and a line drawing of a tyre and were told that there were three main strategies that could be used
to model the part. The learner was then asked to model the tyre using all three strategies [refer to Chapter Two, section 2.2] and subsequently change an important element of the design. This showed the learner that one of the strategies allowed design changes to be made very easily, whereas the other strategies made it very difficult to make design changes to the model. The learner was then provided with an overview of the information at the end of the exercise.

The final section of this version of the material provided a ‘database’ of different products and how they were created, which linked the two previous sections together. The three products that were provided included a desk lamp, a coffee mug and a perfume bottle [refer to Figure 50]. Each example showed the learner how the product had been created on CAD using an effective CMS. A step-by-step guide was provided so that the learner could recreate the parts easily using the defined strategies.

Figure 50: CAD/CAM Achiever - Database of common forms

7.3.3 Overview of the basic features

An overview of all of the basic features in Pro/DESKTOP was also provided, which included basic exercises involving the use of a skateboard, as shown in Figure 51.
Figure 51: CAD/CAM Achiever - Basic features in Pro/DESKTOP

7.3.4 Observations

Although it was not possible to generate formal feedback from the CAD/CAM Achiever material, a number of informal observations were made from trainee teachers who used the software to teach Pro/DESKTOP to KS4 students.

- **Positive aspects of the material**
  - Incentive tutorial – this was seen to be a useful introduction to CAD and helped the students to consider the ‘end goal’
  - ‘Overarching’ approaches – this was felt to be useful in terms of helping the students to plan how they were going to model their designs
  - Tyre example – this was an extremely useful exercise in terms of illustrating the time implications of selecting an inappropriate CMS
  - Database of common forms – this was useful with regard to specific case studies relating directly to the material that had been used, for the student to work through
  - Technology – the electronic nature of the learning material ensured that the learners were engaged in the content, as it allowed them to use the material at their own pace, navigate through the sections as necessary and provided a good platform with which to communicate the content
(e.g. using hyperlinks to relevant strategies within the ‘overarching’ approach section)

- **Negative aspects of the material**
  - ‘Detailed’ approach (groups of similar models) – using groups of similar models was useful if the product to be modelled fell into one of the four groups. However, if, for example, the student wished to model something more complex, involving the use of all tools, this grouping was not effective.

Therefore, in the next version of the CMSS material, it was found to be necessary to further explore the notion of an incentive tutorial and to further develop the ‘overarching’ and ‘detailed’ approach sections as well as the ‘database of common forms’. Also, the tyre exercise was retained as it was seen to be valuable in terms of reinforcing key messages.

### 7.4 Iteration 2: August 2003

The second iteration of the CMSS material was trailed on three occasions, within Pro/DESKTOP courses (9th July 2003, 23rd July 2003 and 18th August 2003). Twelve teachers from the London Borough of Dagenham and Barking and one LEA advisor used the material on the 9th of July and twenty CAD trainers looked at the material on the 23rd July and the 18th August.

### 7.4.1 Description

A tutorial was undertaken as part of the second iteration of the material, to provide an introduction to CMS, as well as an introduction to ‘overarching’ and ‘detailed’ approaches. A group discussion [refer to Chapter Three, section 3.3.3] was then undertaken to establish whether the material was useful to the participants.

The tyre exercise, as noted in section 7.3.2 was used during this iteration, although it was presented in a slightly different format. Initially, the group was split into three and each group was asked to model the tyre using one of three strategies (engineering
drawings of the tyre and step-by-step handouts of how to model the tyre were provided to the participants). When all of the groups had completed the tyre model, they were then asked to alter the number of treads on the tyre and the diameter of the tyre. A group discussion [refer to Chapter Three, section 3.5] then took place regarding the problems involved with changing the design of the tyre and the ‘overarching’ and ‘detailed’ approaches discussed earlier in the session. This also conformed to the social constructivist theory, whereby learners were building up their knowledge by interacting with each other [Pear & Crone-Todd 2001].

### 7.4.2 Observations

The feedback from the three sessions was very positive, where the participants mentioned that the material was useful.

- **Positive aspects of the material**
  - Tutorial (overview of CMS) – this was felt to be useful as the participants had not used any training material that was specifically based on this subject previously.
  - Tyre exercise (group work) – this was felt to be particularly useful with regard to highlighting the issues involved with CMS.

- **Negative aspects of the material**
  - Tyre exercise - although not necessarily negative, it was noted that the tyre exercise might be similarly informative if the participants were allowed to work in pairs.

Therefore, within the next iteration of the material, it was necessary to trial the tyre exercise with the participants working in pairs.

### 7.5 Iteration 3: June 2004

The third iteration of the CMSS material was trailed on the 28th June 2004 and took place during a week-long course for twenty trainee teachers.
7.5.1 Description
During this iteration of the material, a tutorial format was used to communicate the ‘overarching’ approaches section, the ‘detailed’ approaches section and the example tyre exercise [refer to section 7.3.2]. The tutorial described the overall aim of the research and included a definition of CMS and an introduction to the tyre exercise. Again, the group was split into three and the participants were asked to work in pairs (a direct result of the feedback from Iteration 2 of the material). Each group was asked to model the tyre using one of the three different strategies and the groups were told that a good CMS would emerge when they redesigned the tyre. When all of the participants had finished modelling the tyre, they were instructed to change the number of treads and the diameter of the tyre. A group discussion [refer to Chapter Three, section 3.3.3] then took place regarding the problems that were found when redesigning the tyre.

7.5.2 Observations
Again, the feedback from this iteration of the material was very positive.

- Positive aspects of the material
  o Tyre exercise (group work) – the participants found that the tyre exercise highlighted the issues involved with CMS very well.

- Negative aspects of the material
  o Tutorial (overview of CMS) – although the participants could understand the difference between ‘overarching’ approaches and more ‘detailed’ approaches, it was suggested that there should be more detail included regarding how the ‘overarching’ approaches could be implemented using Pro/DESKTOP.

Therefore, it was necessary to build further content into the ‘overarching’ approaches section for the next iteration of the material.
7.6 Iteration 4: August 2004
This iteration of the material was used on the 28th August 2004 and involved eight ITT Lecturers, who were all ‘advanced’ Pro/DESKTOP users.

7.6.1 Description
The tyre exercise [refer to section 7.3.2] was used again in this iteration of the material, although the difference in this example was that the participants were asked to work in pairs, but were allowed to model the tyre using any strategy (without following the step-by-step guides). They were not told beforehand that they would have to change an aspect of the design of the tyre, so that when they did have to change the tyre, the CMS issues were very apparent.

7.6.2 Observations
Again, the feedback from this trial was very positive, although few participants chose to model the tyre by sketching the top profile (the most ineffective strategy), perhaps because they were already advanced users.

- **Positive aspects of the material**
  - Tyre exercise (group work) – this was very useful in terms of highlighting the issues involved with CMS

- **Negative aspects of the material**
  - Tyre exercise (group work) – in a group example, it was felt to be advantageous to stipulate the strategies to be used and to feedback to the group to clearly show the differences between the strategies. It was clear that the most successful version of the tyre exercise was used within Iteration 3 of the material [refer to section 7.5].

7.7 Iteration 5: July 2004
The purpose of Iteration 5 of the material was to formally evaluate all of the aspects of the material that had been tested to date. This version of the material aimed to evaluate
the content of the material and not the technology used to communicate it, so was presented primarily using a paper-based format.

The trial took place on Wednesday 7th July and involved nine A-level students (16 and 17 years old) from Ashby Grammar School. A booklet containing all of the information that was needed for the trial was given to the participants. A photocopy of the electronic exercises was made available to appeal specifically to the ‘Assimilating’ learning style [Kolb et al. 2000]. The trial involved a discussion of work previously undertaken, an introduction to CMS (including the tyre exercise), an introduction to ‘overarching’ approaches and a set ‘project’, which involved designing a memory stick housing.

7.7.1 Discussion of work previously undertaken

The aim of this discussion was to discover which CAD modelling features had been used already by the participants involved in the trial, what project work the participants had used Pro/DESKTOP for, whether they had tried to change any of their designs and also what ‘downstream’ activities the participants had used Pro/DESKTOP for (e.g. rendering, engineering drawings or manufacture).

The participants answered questions about the work they had undertaken previously and completed the first questionnaire [refer to Appendix 3 for an example questionnaire]. They briefly described what projects they had used Pro/DESKTOP for and what features they had used. From this it was noted that the participants had used the basic features and that they had used Pro/DESKTOP in their minor projects for A-level. It was then necessary to record this information in more detail using a questionnaire, which established which specific features and tools the participants had used previously on Pro/DESKTOP and what CAD packages, if any, they had used, other than Pro/DESKTOP.

The majority of participants had used Pro/DESKTOP for approximately one year, with one participant having used it for less than six months and one having used it for over a year. Table 54 shows the number of participants that had used each of the individual features. It was expected that all of the participants had used all of these basic features,
although, as can be seen, the only tool that all of the participants had used was the extrude tool. This meant that some of the material had to be modified slightly in order for all of the participants to progress with the CMSS material. For example, for the first planned exercise (the tyre exercise), it was crucial that the participants understood how to create a revolve, or at the very least, were aware of what the revolve feature was. However, over half of the participants had never used the revolve feature before. It was therefore decided that the group should carry on with the tyre exercise and to ask the participants who had used a revolve before to create the tyre using the revolved strategy, the participant who felt confident using Pro/DESKTOP to create the tyre using the extruded tyre treads strategy and the remainder to use simple extrusions.

<table>
<thead>
<tr>
<th>Tool:</th>
<th>Number of participants that had used the tool before (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamfer</td>
<td>8</td>
</tr>
<tr>
<td>Draft</td>
<td>1</td>
</tr>
<tr>
<td>Extrusion</td>
<td>9</td>
</tr>
<tr>
<td>Insert Holes</td>
<td>8</td>
</tr>
<tr>
<td>Loft</td>
<td>0</td>
</tr>
<tr>
<td>Mirror</td>
<td>3</td>
</tr>
<tr>
<td>Pattern</td>
<td>6</td>
</tr>
<tr>
<td>Project</td>
<td>6</td>
</tr>
<tr>
<td>Revolve</td>
<td>4</td>
</tr>
<tr>
<td>Round</td>
<td>8</td>
</tr>
<tr>
<td>Shell</td>
<td>3</td>
</tr>
<tr>
<td>Sweep</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 54: Pro/DESKTOP tools that participants had used

7.7.2 Tyre exercise

The aim of this exercise was to emphasize the importance of using an effective ‘overarching’ approach by asking three different groups to model a toy tyre using three different CMS [as noted previously in sections 7.3, 7.4, 7.5 and 7.6]. The tyre and strategies that were used within this exercise can be seen in Chapter Two, section 2.2.
Primarily, the group was split into three. The participants that had used a revolve before split into pairs and modelled the tyre using strategy C, one participant modelled the tyre using strategy B and the remainder of the group split into pairs and modelled the tyre using strategy A. One participant from each group was then asked to explain how they had created the tyre. The participants were then asked to change the diameter of the tyre, to make it bigger or smaller. Conclusions were drawn as to which of the strategies were easiest to make design changes to and which had been problematic to change. Some participants mentioned that strategy A was quite problematic with regard to changing the design, as they had to go back into all of the sketches and change them. It was apparent to the participants that strategy B was the most difficult to change and therefore the least effective CMS to use out of the three.

### 7.7.3 Presentations

Two presentations were given to the group to give the participants an introduction to CMS and to ‘overarching’ approaches.

**CMS presentation**

The aim of the CMS presentation was to confirm the notion of CMS as highlighted to the participants by the previous tyre exercise and to give them additional information regarding different types of CMS. The presentation included the following content:

- What the overall aim of the research was – to put the research into context for the participants
- What CMS are
- Introduction to ‘overarching’ approaches and more ‘detailed’ approaches
- Why CMS are an important consideration when designing
- How the participant can ensure that they are using a good CMS
- Introduction to the session
‘Overarching’ and ‘Detailed’ approaches presentation

The aim of the ‘overarching’ and ‘detailed’ approaches presentation was to provide guidance relating to setting up and constructing the participant’s CAD model through the use of different strategies.

The content that was covered included:

- ‘Sharing’ strategy
- ‘Separate’ strategy
- ‘Trial and error’ strategy

7.7.4 Alloy wheel exercise

The participants were then asked to undertake another exercise, introducing the notion of ‘shared geometry’ [as noted in Chapter Four, section 4.4]. The aim of this exercise was to implement the use of the driven design strategy within the context of designing an alloy wheel to fit inside the tyre, which had been created previously. A copy of the tyre file using the revolved strategy was available to the participants. An electronic copy of the exercise was also provided to the participants on each of their computers in order to help them to see some of the illustrations that were not clear in the photocopy. The main aim of this exercise was to show the participants how to create a driven design file and to see first hand the advantages of using the driven design CMS over the use of simple extrudes. The model that the participants were aiming to create on Pro/DESKTOP can be seen in Figure 52.

![Figure 52: Alloy wheel part](image)

The participants were asked to model an alloy wheel that fits exactly inside the tyre, so when the tyre is changed, the alloy wheel will also change. They were provided with a
step-by-step guide to creating this part. Unfortunately, this exercise was quite unsuccessful for two reasons:

1. The original tyre file (that five of the participants were using) was saved on the same u:// space, which caused problems when the participants attempted to modify the file at the end of the exercise as all of the participants were attempting to modify the same file. The file should have been copied onto the individual hard drives before the exercise had started.
2. The exercise was too complicated for some of the participants to follow.

Three of the participants followed the exercise successfully and created an alloy wheel using the driven design strategy that changed size automatically when the tyre was redefined. However, as many of the participants could not use all of the basic features, it was decided to move onto the memory stick project early and to give a demonstration of the driven design file using the projector.

**7.7.5 Memory stick project**

The aim of the memory stick project was to design the casing to house the ‘Intelligent Stick’, applying the information that the participants had been given earlier in the trial to their CMS. The participants were given a Pro/DESKTOP model of the ‘Intelligent Stick’ and engineering drawings to create their design. They were instructed to design their Pro/DESKTOP model in a way that would allow the memory stick to be changed in length. This project was very successful, with the majority of participants having created a model successfully and the remainder planning to finish the design during their own time.

**7.7.6 Observations**

In order to evaluate the material that the participants had been given during the trial, the participants were asked to fill in a questionnaire [refer to Appendix 3 for an example questionnaire]. As noted previously, the aim was to evaluate the content of the material and not the technology used.
• **Positive aspects of the material**
  o 90% of the participants said that overall the content of the material was either ‘helpful’ or ‘very helpful’. This included the tyre exercise, the presentations, the alloy wheel exercise and the memory stick project.
  o Seven out of the nine participants mentioned that they thought it would be important to teach this content and that it would make them think differently about the way that they would model on CAD.

• **Negative aspects of the material**
  o Only five participants thought that the exercises were easy to follow (the remainder selected ‘no feeling’) and two participants had problems with the material.
  o The two participants that had problems with the material mentioned that the reasons that they were having problems were that ‘I messed up’ [P704] and that ‘I found it hard to follow the instructions as my computer kept showing error messages’ [P706]. Again, this shows the importance of showing the learners how to recover from error messages, which was envisaged to form part of the ‘feature-based’ approach [refer to Chapter Two, section 2.3.1].

When asked to comment on how the content could be improved, three of the participants noted that they would like to see more step-by-step instructions on how to complete the required tasks. When asked to list suggestions for content that should be added, responses included ‘Instead of saying what needs to be done, it should tell you how to do it’ [P708].

**7.8 Summary**

A number of different iterations of the CMSS material were created in order to gain feedback about the material before the main PhD trial. In terms of compatibility of the Pro/DESKTOP material with Pro/ENGINEER, it was envisaged that there would not be any major changes to make to the CMSS material, as the majority of the material is not software specific. The material had been developed through feedback from the various
participants who used the material within an educational context. The material was first used within the CAD/CAM Achiever to establish the effectiveness of the prototype material. It was then used within Pro/DESKTOP courses, which led to the design of the final version of the prototype material, used in the main trial of the material in July 2004.

Although there was no formal feedback from the CAD/CAM Achiever material, this version was used within Pro/DESKTOP courses, for which positive feedback was received. The participants noted that the material was helpful and that the tyre exercise was particularly useful with respect to highlighting the issues involved with CMS. As the different versions of the material emerged, it was clear that the participants were able to understand the difference between ‘overarching’ approaches and more ‘detailed’ approaches.

The main Pro/DESKTOP trial was very important with regard to establishing which elements of the material worked and which still needed developing. It was obvious that some of the material was too complicated for participants that were fairly inexperienced on Pro/DESKTOP, although it worked well for those who had more experience. The main aspect of the material that changed as a result of the trial was the alloy wheel exercise, where it may be more appropriate to use a different approach to create the driven design model.

Several elements gained positive feedback and were therefore used to build the final version of the CMSS material:

1. Inclusion of a general overview to CMS presentation, as well as an introductory presentation
2. Use of ‘overarching’ and ‘detailed’ approaches – using probing questions to define a strategy as well as information regarding how the strategies can be implemented using the CAD system
3. Use of the tyre exercise – working in pairs
4. Use of an incentive tutorial
5. Inclusion of a database of common forms
6. Inclusion of shared geometry exercises

Therefore the next chapter describes the final version of the material, used within the main PhD trial.
8 FINAL CMSS MATERIAL

Overview: This chapter provides an overview of the final CMSS material that was developed for use within the main PhD trial.

8.1 Introduction

This chapter provides an overview of the final version of the CMSS material, which was used in the main PhD trial. This version of the material was generated through the numerous Pro/DESKTOP trials [refer to Chapter Seven], and is documented fully in Appendix 9. The focused research aim that this chapter explores can be seen in Table 55:

<table>
<thead>
<tr>
<th>Focused research aim: Final CMSS material</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To generate an accurate description of what should be included in the CMSS material and consider the methods with which to communicate this information effectively to novice CAD users.</td>
</tr>
</tbody>
</table>

Table 55: Focused research aim from Chapter Two [refer to section 2.7]

A specific research objective was then generated, as can be seen in Table 56:
Specific research objective: Final CMSS material

- To develop a final version of the CMSS material, for use within the main PhD trial.

Table 56: Specific research objective - Final CMSS material

8.2 Design of the material
The final version of the CMSS material was presented as a blended learning offering, which combined interactive, web-based material with printed aspects, tutorials and group work. Additionally, before the learner could access any of the information, they were required to ‘log in’. The log-on page was useful to generate statistical information about the users of the online material, for example, how often they visited the site.

8.3 Print-based material
The print-based materials used within the main PhD trial included:

- Printed CAD exercises (shared geometry exercises, tyre exercise)
- Printed introductory booklet
- Introductory PowerPoint presentation
- CMS PowerPoint presentation
- Printed presentation boards

The printed CAD exercises acted as an incentive to undertake the learning [refer to Chapter Seven, section 7.3.1], as did the presentation boards. The aim of this element was to ensure that the learner understood what could be achieved if they continued to use the material. In Pilot Study One [refer to Chapter Four, section 4.4], it was found to be necessary to ensure that learners were shown the potential to exploit the CAD model and to learn how to make use of shared geometry. Also, by providing the learners with a step-by-step exercise, it was possible to provide them with clear examples of how those features that were perceived as more ‘complicated’ could be used [refer to Chapter Four, section 4.4]. The tyre exercise was used to illustrate to the learner the time
implications of using an ineffective method with which to model on CAD and the benefits of using an effective method [refer to Chapter Four, section 4.4].

8.3.1 Printed CAD exercises (shared geometry exercises)
Four CAD exercises were used (profile-profile, reference-reference, pattern and duplicate part), which aimed to guide the learner through the notion of shared geometry [refer to Appendix 6]. A key outcome from Pilot Study One and previous literature [Richards 1995, Mahoney 2000] was that parallels should be drawn between the product being modelled and the tangible ‘real-life’ object, so both CAD exercises involved ‘real-life’ examples.

8.3.2 Printed introductory booklet
The introductory booklet detailed the format and timings for the session and the website address that the learner needed to visit. It also detailed the prerequisites for using the material, which included the learner:

- Knowing what product they were going to model for their University assignment
- Knowing how many parts there were in their chosen product
- Having logged onto the CMS section of the University ‘Learn Server’ successfully

It also asked the learner to record their user number for the web-based material, which was important from an administration point of view.

8.3.3 Introductory PowerPoint presentation
The Introductory PowerPoint presentation provided the learner with a basic introduction to CMS. Both the PowerPoint presentations were developed as a result of the previous Pro/DESKTOP trials [refer to Chapter Seven, section 7.7.3]. The slides can be seen in Appendix 9. The aim of this presentation was to give the learners a clear understanding of what they would be expected to do, as well as timescales for the research. Detailed information was also provided regarding the introductory session.
8.3.4 CMS PowerPoint presentation
An additional PowerPoint presentation was then provided, giving the learner more
detailed information about ‘overarching’ approaches. This presentation can be found in
Appendix 7.

8.3.5 Printed presentation boards
Printed presentation boards were used to provide a further visual introduction to the
subject, and were originated from the research carried out in the ‘Exploratory Study’ [Chapter Two]. The presentation boards can be seen in Chapter Two, section 2.4.2. The
presentation boards provided case study examples of effective and non-effective CMS.

8.4 Interactive web-based material
The following section details the interactive web-based aspect of the CMSS material
and included a description of:

- ‘Home’ – this allowed the learner to view an overview of what was contained
  within each section of the material
- ‘Previous Material’ – this allowed the learner to view all of the material that had
  been presented to them in the ‘Introductory Session’
- ‘The Strategy’ section – this was the main section of the material and allowed
  the learner to generate a printable CMS for any product that they needed to
design
- ‘Support Material’ – this contained an interactive section, help section and a
  database of common forms if the learner required assistance

8.4.1 Home page
The Home Page of the online material provided the learner with a list of the different
sections contained within the online material.

8.4.2 Previous material
The previous material page contained all of the information used in the introductory
session of the main research trial [refer to Chapter Nine]. It was necessary to include the
material used within the introductory session within the online material to ensure that
the learner could revisit the information at a later date, to allow them to learn in their
own time. A screen print of the ‘Previous material’ page can be seen in Appendix 9.

8.4.3 ‘The Strategy’
‘The Strategy’ section, detailed in Appendix 9, was the main strategic element of the
CMSS material. It encouraged the learner to think about the key aspects, identified in
Chapter Five, that are necessary in order to select an effective CMS. It provided the
learners with a formal planning process, to help them to consider the modifications that
would have to be made to the model.

8.5 Support material
The support section allowed the learner to access three main sections.

- Interactive section
- Help section
- Database of common forms

8.5.1 Interactive section
The interactive section contained a link to a discussion list, to allow the learners to
interact with CAD users of varying abilities and to post messages if they were having
difficulties.

8.5.2 Help section
The ‘help’ section included the option to email an expert user, contained helpful links
and also contained a frequently asked questions section

8.5.3 Database of common forms
The ‘database of common forms’ section contained several different products that were
considered to be key products for product designers. This section had been used within
the CAD/CAM Achiever Pro/DESKTOP trial [refer to Chapter Seven, section 7.3.2 and Appendix 6].

8.6 Summary
The final prototype of the CMSS material was presented as a blended learning offering, which combined interactive, web-based material with printed aspects, tutorials and group work. The next stage was therefore to evaluate the CMSS material using novice CAD users.
9 MAIN STUDY AND RESULTS

Overview: This chapter documents the main PhD trial, involving the implementation and evaluation of the final CMSS material.

9.1 Introduction

Having created the final CMSS material, the final stage was to evaluate it using novice CAD users learning to use Pro/ENGINEER for the first time and to discover whether they were more efficient\(^{17}\) CAD users as a result of having used the material. The evaluation took place between December 2004 and June 2005. The focused research aim that this study addressed can be seen in Table 57.

<table>
<thead>
<tr>
<th>Focused research aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>To establish whether the CMSS material produces a more efficient CAD user</td>
</tr>
</tbody>
</table>

Table 57: Focused research aim from Chapter Two [section 2.7]

This was carried out in two separate phases, as can be seen in Table 58:

\(^{17}\) More efficient was defined as the CAD user being able to capture their design intent having used an efficient CMS, which would theoretically allow them to make design changes to their model easily
Stages of the Main Study | Methods used [Refer to Chapter Three, section 3.6]
--- | ---
Stage 1: Implementation of the final version of the CMSS material (as detailed in Chapter Eight)  
To use the CMSS material to communicate effective CMS to novice CAD users learning Pro/ENGINEER for the first time  
• ‘Before and after’ study  
• Presentation  
• CMSS material [refer to Chapter Eight]  
• Support sessions [refer to Chapter Eight]

Stage 2: Evaluation of the final version of the CMSS material (as detailed in Chapter Eight)  
To evaluate the CMSS material to discover whether it produces a more efficient CAD user  
• CAD exercise  
• Interviews, coding and clustering data [Miles & Huberman 1984], consideration of emerging themes  
• Questionnaires [refer to Appendix 3]  
• CAD: analysis of CAD models, analysis of timed CAD exercise

Table 58: Stages of the Main Study and research methods

9.2 Design of the study
A crucial aspect of creating a successful learning resource is evaluating it and the method used within this research stems from Kirkpatrick’s [1998] four level evaluation process. Kirkpatrick lists a number of factors that should be considered when planning and implementing a successful training programme [1998:3], as can be seen in Table 59:
### Factors to consider when designing and implementing a successful training programme [1998:3]

| Determining needs | Chapter One (Introduction)  
| Chapter Two (Exploratory Study) |
| Setting objectives | Chapter Eight (Final CMSS material) |
| Determining subject content | Chapter Four (Pilot Study One)  
| Chapter Five (CMSS Material - Content Definition)  
| Chapter Six (Teaching & Learning)  
| Chapter Seven (Pilot Study Two)  
| Chapter Eight (Final CMSS material) |
| Selecting participants | Chapter Nine (Main Study and Results) |
| Determining the best schedule | Chapter Eight (Final CMSS material) |
| Selecting appropriate facilities | Chapter Eight (Final CMSS material) |
| Selecting appropriate instructors | Chapter Eight (Final CMSS material) |
| Selecting and preparing audiovisual aids | Chapter Eight (Final CMSS material) |
| Coordinating the programme | Chapter Nine (Main Study and Results) |
| Evaluating the programme | Chapter Nine (Main Study and Results)  
| Chapter Ten (Discussion)  
| Chapter Eleven (Conclusion and Future Directions for Research) |

**Table 59: Factors to consider when designing and implementing a successful training programme [Kirkpatrick 1998:3]**

The remainder of the chapter has been split into three sections, per Table 59:

- Selecting participants [refer to section 9.3]
- Coordinating the programme [refer to section 9.4]
- Evaluating the programme [refer to section 9.5]

### 9.3 Selecting participants

A ‘before and after study’ [Kumar 1996] was used within the Main Study to ensure that the material could be tested on two groups of participants of similar abilities, where one group had been exposed to the material and one group had not. Using a ‘before and after study’ [Ibid] ensured that comparisons could be made between the groups. A Year
One\textsuperscript{18} coursework assignment (‘Assignment One’ – see Appendix 8) was used as the CAD exercise within the Main Study. It was deemed to be an appropriate time for Year One students to be exposed to the CMSS material, as they had been taught how to use all of the basic features on Pro/ENGINEER. However, it should be noted that ‘Assignment One’ was the first time the participants had implemented \textit{all} of the features that they had been taught in one model. Having examined ‘Assignment One’ in detail, it was considered an appropriate means of testing the material for the following reasons:

- It gave the participants the opportunity to pick from a finite number of products (hand-held hole punch, stapler, mobile phone or pocket calculator, based on a real-life object). The researcher modelled each of the products, to ensure that they could be modelled using a number of different strategies and were therefore suitable for use in the research [refer to Figure 53]. It was noted that a number of different strategies could be used to model the products and would therefore provide useful data with relation to CMS.
- The timing of the assignment was ideal in terms of the research plan, in that the participants started the assignment in December and submitted their models at the end of January. This provided the researcher with a number of months in order to undertake a thorough analysis of the results. The evaluation was then undertaken in April, which again, provided the researcher with a number of months to analyse the data.
- The assignment criteria [refer to Appendix 8] was standard across the year.
- In order to pass ‘Assignment One’, the model had to look \textit{realistic} (although it should be noted that the participants were not required to create a very detailed model, as this was the first time they had implemented all of the features in one model).

However, there were also some weaknesses that were noted in relation to using ‘Assignment One’:

\textsuperscript{18} Year One refers to Year One Undergraduates on Industrial Design and Technology at Loughborough University 2004 - 2005
• ‘Assignment One’ was based on a real product and could therefore be viewed as a ‘reverse engineering exercise’ as opposed to a full ‘design’ exercise.
• The assignment was ‘open ended’ in that the brief was to design a ‘generic’ product as opposed to a specific product. This could be seen as a disadvantage, as the participants could be modelling different versions of the same product, making it problematic to make specific comparisons.

The overall strategy for the evaluation was to deliver the CMSS material to the CMS Group before they undertook ‘Assignment One’ and to undertake a thorough evaluation of the models submitted from both groups (the CMS Group and the Control Group) to make judgements about the effectiveness of the CMSS material.

Figure 53: Researcher’s models of a calculator, hole punch, mobile phone and stapler

9.3.1 Sampling strategy
The sampling strategy used for the evaluation was carried out in two phases:
• All students in Year One were contacted and asked to volunteer for the research. Of the 120 students, 11 were selected to take part in the study, as can be seen in the column CMS Group in Table 60.

• The participants in the CMS Group were then matched as closely as possible with other members in Year One in order to select pairs of students with equal abilities to form a Control Group. The criteria used to match the ‘pairs’ were:

  o The CAD package(s) they had used previously
  o Their use of the CAD package(s), e.g. whether they used it significantly (e.g. to develop their design ideas) or non-significantly (e.g. to undertake simple CAD exercises)
  o Their mark for the initial ‘Perfume Bottle Assignment’, where they were asked to demonstrate that they could use all the features
  o Their A-level course

The ‘pairs’ were matched as closely as possible, where the CAD package was used to match the participants primarily, followed by their subsequent use of the CAD package. Several other sampling strategies had been considered that were not used, including testing the CMSS material on the entire year and testing the CMSS material on half the year, although they were subsequently rejected due to issues with the validity of the data.

9.3.2 Participants
The group subjected to the CMSS material has been termed the CMS Group and their ‘pairs’ termed the Control Group. From an ‘Introductory Questionnaire’ [refer to Appendix 3], it was found that the participants had varying levels of CAD experience, as can be seen in Table 60, where the ‘pair’ of each participant in the CMS Group can be seen on the same row.
<table>
<thead>
<tr>
<th>CMS Group</th>
<th>CAD Experience</th>
<th>Control Group</th>
<th>CAD Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant Number</td>
<td></td>
<td>Participant Number</td>
<td></td>
</tr>
<tr>
<td>P901A</td>
<td>Used Pro/DESKTOP for Exercises (Minimal Use)</td>
<td>P901B</td>
<td>Used Pro/DESKTOP for Exercises (Minimal Use)</td>
</tr>
<tr>
<td>P902A</td>
<td>No Usage</td>
<td>P902B</td>
<td>No Usage</td>
</tr>
<tr>
<td>P903A</td>
<td>No Usage</td>
<td>P903B</td>
<td>No Usage</td>
</tr>
<tr>
<td>P904A</td>
<td>Used Pro/DESKTOP for Exercises, Rendering, Development, Working Drawings (Extensive Usage)</td>
<td>P904B</td>
<td>Used Pro/DESKTOP for Exercises, Rendering, Development, Working Drawings (Extensive Usage)</td>
</tr>
<tr>
<td>P905A</td>
<td>Used Pro/DESKTOP for Exercises and Renderings (Minimal Usage)</td>
<td>P905B</td>
<td>Used Pro/DESKTOP for Exercises and Renderings (Minimal Usage)</td>
</tr>
<tr>
<td>P906A</td>
<td>Used Pro/DESKTOP for Exercises, Renderings and Working Drawings (Medium Usage)</td>
<td>P906B</td>
<td>Used Pro/DESKTOP for Exercises, Renderings and Working Drawings (Medium Usage)</td>
</tr>
<tr>
<td>P907A</td>
<td>Used Inventor for Exercises, Rendering, Working Drawings (Medium Usage)</td>
<td>P907B</td>
<td>Used Inventor for Exercises, Rendering, Working Drawings, CNC (Extensive Usage)</td>
</tr>
<tr>
<td>P908A</td>
<td>No Usage</td>
<td>P908B</td>
<td>No Usage</td>
</tr>
<tr>
<td>P909A</td>
<td>Used Pro/DESKTOP for Exercises, Rendering</td>
<td>P909B</td>
<td>Used Pro/DESKTOP for Exercises, Rendering</td>
</tr>
<tr>
<td>P910A</td>
<td>Used Pro/DESKTOP and SolidEdge for Exercises, Rendering, Development and Working Drawings (Extensive Usage)</td>
<td>P910B</td>
<td>Used Pro/DESKTOP and Inventor for Exercises, Rendering, Development and Working Drawings (Extensive Usage)</td>
</tr>
<tr>
<td>P911A</td>
<td>Used Pro/DESKTOP for Exercises and Working Drawings (Minimal Usage)</td>
<td>P911B</td>
<td>Used Pro/DESKTOP for Exercises, Rendering and Working Drawings (Medium Usage)</td>
</tr>
</tbody>
</table>

Table 60: Participants used in the Main Study and their previous CAD experience
Again, it can be seen that there was a relatively even split of learners involved in the study, ranging from no CAD experience at all, through to extensive prior CAD experience [refer to Figure 54].

![Figure 54: Participants’ CAD experience](image)

This shows that an equal range of learners were involved in the PhD evaluation.

### 9.4 Implementation of the CMSS material - Coordinating the programme

[Kirkpatrick 1998]

The implementation of the Pro/ENGINEER version of the CMSS material was undertaken in December 2004. The specific aim of this part of the study was to deliver the material to the eleven Year One students, termed the CMS Group, in order to allow the participants to evaluate the material at a later stage.

The principles of adult learning, as noted by Knowles [1984a] in Chapter Six, were applied to the material as shown in Table 61.
<table>
<thead>
<tr>
<th>Element of adult learning [Knowles 1984]</th>
<th>Where this has been considered within the research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate setting. What procedures would be most likely to produce a climate that is conducive to learning? [Ibid:14]</td>
<td>As a ‘before and after’ study [Kumar 1996] was used within the research, it was necessary to replicate the learning conditions that the Control Group was facing. Therefore, CAD laboratories were used.</td>
</tr>
<tr>
<td>Involving learners in mutual planning. What procedures can be used to get the participants to share in the planning? [Ibid:17]</td>
<td>By answering key questions about their product, and receiving a personalised strategy output, it was possible to involve learners in the mutual planning of their learning.</td>
</tr>
<tr>
<td>Involving participants in diagnosing their own needs for learning. What procedures can be used for helping learners responsibly and realistically identify what they need to learn? [Ibid:17]</td>
<td>By showing the learners that the advantages and disadvantages of using different CMS (e.g. the tyre exercise, shared geometry exercises), it was possible for the learners to identify the need for them to learn.</td>
</tr>
<tr>
<td>Involving learners in formulating their learning objectives. What procedures can be used to help learners translate their diagnosed needs into learning objectives? [Ibid:18]</td>
<td>By showing the learners the advantages of using an effective CMS, it helps them to understand why they need to learn and then formulate their own learning objectives.</td>
</tr>
<tr>
<td>Involving learners in designing learning plans. What procedures can be used to help the learners identify resources and devise strategies for using these resources to accomplish their objectives? [Ibid:18]</td>
<td>The strategy output acted as a plan for the learners to implement the CMSS material into their own model, enabling them to accomplish their objectives.</td>
</tr>
<tr>
<td>Helping learners carry out their learning plans. [Ibid:18]</td>
<td>Weekly support sessions were held in order to help the learners achieve their objectives as necessary.</td>
</tr>
<tr>
<td>Involving learners in evaluating their learning. [Ibid:18]</td>
<td>All learners were invited to take part in the evaluation of the material and their learning.</td>
</tr>
</tbody>
</table>

Table 61: Application of Andragogy [Knowles 1984a] in the design of the CMSS material

9.4.1 Logistics

In order to provide the CMS Group with the CMSS material it was important to ensure that the participants were provided with:
• **An introductory session**
   The introductory session ensured that the participants in the CMS Group were given an overview of the material.

• **Access to the CMSS material**
   It was vital to ensure that all participants understood how to log onto the CMSS material and had done so at least once during the introductory session.

• **Support sessions**
   Support sessions were necessary to ensure that the participants in the CMS Group were not disadvantaged against their peers (who had the opportunity to attend CAD support sessions).

**Introductory session**
The introductory session took place at the beginning of ‘Assignment One’ and covered the fundamentals of the CMSS material. To supplement the CMS web-based material, the participants were asked to fill in a consent form and were given an overview presentation [refer to Chapter Eight], which provided a summary of the research that was being undertaken and an introduction to the session that they would be attending. Additionally, the participants had access to five presentation boards [refer to Chapter Two] aimed at conveying the fundamentals of CMS to the participants, in particular:

- The different strategies that had been identified
- Examples that highlighted the implications of using different strategies
- The importance of using a good feature level strategy

A presentation on CMS was then given to the participants, which provided them with an outline of what CMS are, the types of strategies identified and why they are important [refer to Chapter Five], as well as an introduction to the CMSS material [refer to Chapter Eight].

The participants were then asked to undertake the four exercises in the ‘Previous Material’ section of the CMSS material [refer to Appendix 6]. The shared geometry exercises were created in order to allow the participants to experience first hand what
they had been shown in the CMS presentation [refer to Appendix 7], which was considered to be an important aspect of the learning process. Part files were available to download, in order to maximise the participants’ attention span by minimising the time they spend on ‘unnecessary’ tasks. All of the exercises used the same example product (a satellite navigation device) and the exercises covered:

- How to implement the ‘profile-profile’ strategy by sharing the geometry of the screen of the GPS device between the top shell and the screen part
- How to implement the ‘reference-reference’ strategy by sharing the datum point geometry to create structural pillars inside the shells of the top and bottom half of the GPS device
- How to implement the ‘pattern’ strategy by creating a row of buttons using the pattern feature
- How to implement the ‘duplicate part’ strategy by creating a mirrored copy of the top half of the GPS device to use as the bottom housing of the GPS device

Access to the CMSS material
Additionally, the participants were given a booklet that provided them with an overview of the format for the introductory session, the web address and information about using the CMSS material. They were all asked to log on and explore the CMSS material. Statistics were generated relating to the usage of the CMSS material, to discover whether all of the participants actively used the material. Data were collected relating to the ‘number of requests per month’ for the material. The number of requests relates to how many times a request for a page was made and access to the CMSS material was restricted to ensure that the Control Group did not have access.
As can be seen in Figure 55, the greatest usage of the CMSS material was made in December and January. The assignment was due in at the end of January and the statistics for usage of the material show that it was utilised frequently in December, perhaps when the participants were in the early stages of the assignment and slightly less in January. It makes sense that the material was not used frequently in the weeks following the hand in of the first CAD assignment (February), which was also an inter-semester break. The Easter break (roughly 4 weeks) took place during March and April, which again, would explain why the usage dropped during these months.

Encouragingly, the CMSS material was utilised more frequently at the end of the academic year, in June, which may be the result of the participants using the material for their final CAD assignment. Another set of statistics were necessary to discover which of the participants used the CMSS material, to ensure that the participants made significant use of the material. It was also necessary to establish whether there were any participants that did not make use of the material, in which case they would have been excluded from the dataset. This can be seen in Figure 56.
This shows that all of the learners made good use of the CMSS material, with all of them making at least 60 requests on the online material (requests being the number of times a page was used), some making over 400 requests during the period of December 2004 to June 2005.

**Support sessions**

Support sessions were held on a weekly basis and were attended on average by five to ten participants. The researcher answered any questions that the participants had relating to CMS, which was considered an important aspect of the CMSS material [refer to Chapter Four and Chapter Six], and also mirrored the support that the Control Group received.
### Implementation of the final version of the CMSS material

- Eleven participants were given an introduction to the CMSS material and had the opportunity to use the material over the course of their main CAD assignment (‘Assignment One’). They also had the opportunity to attend support sessions on particular issues relating to CMS when necessary.
- The participants used the CMSS material significantly during the period of December 2004 and January 2005.

### 9.5 Evaluation of the CMSS material – Evaluating the programme [Kirkpatrick 1998]

Having implemented the CMSS material, it was then necessary to evaluate the effectiveness of the material. The overall aim of the study was to discover whether using the CMSS material helped novice CAD users become more competent at modelling on Pro/ENGINEER. Kirkpatrick’s [1998] levels of evaluation provided useful information on the evaluation of training programmes, as can be seen in Table 62.
Level | Kirkpatrick’s description | Kirkpatrick’s examples | Evaluation tool used
--- | --- | --- | ---
2. Learning | ‘Learning can be defined as the extent to which participants change attitudes, improve knowledge, and/or increase skill as a result of attending the program’ [1998:20] | Use of an experimental group and a Control Group [1998:39-47] | CAD model analysis Questionnaire Interview
3. Behaviour | ‘Behavior can be defined as the extent to which change in behaviour has occurred because the participant attended the training program’ [1998:20] | Use of an experimental group and a Control Group [1998:48-58] | CAD model analysis Questionnaire Interview
4. Results | ‘Results can be defined as the final results that occurred because the participants attended the program’ [1998:23] | Use of an experimental group and a Control Group [1998:59-66] | CAD model analysis CAD model exercise

Table 62: Kirkpatrick’s levels of evaluation [1998]

9.5.1 Specific research questions
The specific research questions used in the evaluation section of the research evolved as a result of the earlier definition of ‘effective’ CMS [refer to Chapter Two, section 2.2], which was termed as:

*Using the most effective features to create an accurate CAD model of a design/concept, allowing key design changes to be implemented quickly and efficiently.*
[Refer to Chapter Two section 2.2]
Initially, it was necessary to ensure that all of the participants within the CMS Group had created realistic looking models, as it would have been unfair to assume that the CMSS material was a success, if the models that were produced were not an accurate representation of the real-life product. This was possible by accessing the final marks for ‘Assignment One’, as part of the criteria for passing the assignment was that they had created realistic looking models. Having accessed the final marks for the assignment, it was found that all of the participants in the CMS Group had passed the assignment and had therefore created realistic looking CAD models. All CAD models produced by both the CMS Group and the Control Group can be found in Appendix 5.

Therefore, in order to discover whether the participants that had used the material had used an ‘effective’ CMS, it was necessary to answer the questions detailed in Table 63.

<table>
<thead>
<tr>
<th>Specific research questions: Evaluation of the CMSS material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did the CMS Group use any of the strategies described in the CMSS material to create their model?</td>
</tr>
<tr>
<td>Did the CMS Group use a more effective strategy than the Control Group?</td>
</tr>
<tr>
<td>Could members of the CMS Group make design changes in less time than members of the Control Group?</td>
</tr>
<tr>
<td>Did the CMS Group feel that the material had helped them?</td>
</tr>
<tr>
<td>What was good about the material?</td>
</tr>
<tr>
<td>What could be improved?</td>
</tr>
</tbody>
</table>

Table 63: Specific research questions: Evaluation of the material

Answering specific research questions
Having generated some specific research questions, it was necessary to establish which research methods were most appropriate to obtain the necessary data. The chosen research methods can be seen in Table 64.
<table>
<thead>
<tr>
<th>Specific research questions</th>
<th>Kirkpatrick’s level</th>
<th>Research method(s)</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Question one:</strong> Did the CMS Group use any of the strategies described in the CMSS material to create their model?</td>
<td>Learning (2) Behaviour (3)&lt;sup&gt;19&lt;/sup&gt;</td>
<td>Analysis of CAD models from the CMS Group</td>
<td>By analysing the CAD models of the CMS Group, it would be possible to discover whether they had used any of the strategies presented to them in their models.</td>
</tr>
<tr>
<td><strong>Question two:</strong> Did the CMS Group use a more effective strategy than the Control Group?</td>
<td>Learning (2) Behaviour (3)</td>
<td>Analysis of CAD models Verification of analysis from ‘practiced’ CAD users</td>
<td>By analysing the CAD models in detail, it would be possible to make a judgement about the strategies used, ensuring that the results are not biased through verification of the analysis by two ‘practiced’ CAD users.</td>
</tr>
<tr>
<td><strong>Question three:</strong> Could members of the CMS Group make design changes in less time than members of the Control Group?</td>
<td>Results (4)</td>
<td>Redesign exercise – members of the CMS Group and the Control Group</td>
<td>By asking members of both the CMS Group and the Control Group to undertake a redesign exercise it would be possible to see who could make the changes to their design in the least amount of time.</td>
</tr>
<tr>
<td><strong>Question four, five and six:</strong> Did the CMS Group feel that the material had helped them? What was good about the material? What could be improved?</td>
<td>Reaction (1)</td>
<td>Interview Questionnaires</td>
<td>By conducting both interviews and questionnaires, it would be possible to gain both quantitative and qualitative data regarding the feedback of the CMSS material.</td>
</tr>
</tbody>
</table>

Table 64: Specific research questions, research methods and rationale for evaluation

Therefore, the remainder of this chapter has been split according to the research questions above.

---

<sup>19</sup> All instances of ‘Behaviour’ in this table relate to short-term behaviour of the participants and further investigation is required to establish the long-term effects
9.5.2 Specific research question one

Did the CMS Group use any of the strategies described in the CMSS material to create their model?

Research method

To answer this question, the CAD models from the CMS Group were carefully and thoroughly analysed. It was necessary to discover whether learning had taken place with regard to the learners changing their attitudes and behaviour when modelling on CAD, conforming to Levels 2 (‘Learning’) and 3 (‘Behaviour’) of Kirkpatrick’s levels of evaluation [1998].

Data collection method

All 22 CAD models were analysed - an example of the analysis for one participant can be found in Appendix 5.

Data analysis method

A judgement was made about whether the CMS Group had used any of the CMS in their models, if yes could be answered to one the following statements:

- The participant has used the ‘symmetry’, ‘revolve’ or ‘sweep’ strategy appropriately
- The participant has used the ‘profile-profile’ strategy
- The participant has used the ‘reference-reference’ strategy
- The participant has used the ‘pattern’ strategy
- The participant has used the ‘duplicate part’ strategy

Results

As expected, 100% of the CMS Group had chosen to use one or more of the strategies presented to them through the use of the CMSS material and the introductory session.
<table>
<thead>
<tr>
<th>Summary: Specific research question one</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 100% of the CMS Group had implemented at least one of the strategies presented to them.</td>
</tr>
</tbody>
</table>

9.5.3 Specific research question two

*Did the CMS Group use a more effective strategy than the Control Group?*

**Research method**

Having thoroughly and carefully analysed all 22 models, it was necessary to establish on a part-by-part basis, which of the groups had used more effective strategies to model their products. Theoretically, if the CMS Group had used an effective strategy, especially in comparison to their pairs, this should allow them to make design changes to their model quickly and easily. In terms of Kirkpatrick’s levels of evaluation [1998], this provided final results that occurred because the participant was involved in the research, conforming to Level 4 (‘Results’).

**Data collection method**

An analysis of CAD models was undertaken for all 22 participants. An example of the analysis for one participant can be found in Appendix 5.

**Data analysis method**

A judgement was made by the researcher about whether the participant had used an effective CMS by assigning each part created a score – either 1, 2 or 3 out of 3, based on the following criteria:

- **1: Poor strategy**
  - A *poor strategy* has been used in terms of modelling technique for redesign
Many aspects of this part could have been created in an easier and more effective way

- **2: Reasonable strategy**
  - A **reasonable strategy** has been used in terms of modelling technique for redesign
  - Some aspects of this part could have been created in an easier and more effective way
  - The model tree could be more concise and some aspects are unnecessary

- **3: Good strategy**
  - A **good strategy** has been used in terms of modelling technique for redesign
  - The part was created in the **easiest and most effective way**
  - The model tree is concise and **does not contain any unnecessary aspects**

The part files that did not involve an obvious choice in strategies (e.g. a screen shape profile which had been extruded) were removed and 65 part files in the CMS Group and 62 in the Control Group were analysed and scored. A sample of parts (every 20th part file) was given to two ‘practiced’ CAD users, to score using the same criteria, in order to verify and triangulate the scores that the researcher had given. Only one of the twelve models produced a discrepancy in the scores, although it was agreed that either score would have been appropriate for this particular part.

**Results**

Figure 57 shows the results of the CAD model analysis. The bars shown in red represent the CMS Group and those in black represent the relevant pair within the Control Group.
Figure 57: Results of the CAD model analysis

The full results of the analysis of the strategies used by all participants can be found in Appendix 10 and show that the CMS Group as a whole had used a more efficient detailed approach to those subjected to ‘normal’ CAD input.

<table>
<thead>
<tr>
<th>Summary: Specific research question two</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Through the use of the CMSS material, the CMS Group had used a more effective strategy than the Control Group.</td>
</tr>
<tr>
<td>• Theoretically, the CMS Group should be able to make amends to their model quickly and easily.</td>
</tr>
</tbody>
</table>

9.5.4 Specific research question three

*Could members of the CMS Group make design changes in less time than members of the Control Group?*
Research Method

In order to establish whether the CMS Group, who had seemingly used more effective strategies on the whole than the Control Group, could therefore make design changes to their models more easily, it was decided to use a redesign exercise using Pro/ENGINEER. As previously established [refer to Chapter Two], a key trait of effective CAD users is the ability to make design changes to their CAD model, so it was important to undertake this exercise where the emphasis was on redesign. In terms of Kirkpatrick’s levels of evaluation [1998], this provided final results that occurred because the participant was involved in the research, conforming to Level 4 (‘Results’).

The first stage was to discover which aspects of the various models should be changed. Having created all of the models for the assignment using Pro/ENGINEER, three key aspects were chosen that could potentially require ‘redesigning’, of seemingly equal levels of ‘difficulty’ on each of the models, as can be seen in Table 65.

<table>
<thead>
<tr>
<th>Product</th>
<th>Change 1</th>
<th>Change 2</th>
<th>Change 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculator</td>
<td>Make the calculator wider</td>
<td>Make the button height smaller</td>
<td>Make the screen wider</td>
</tr>
<tr>
<td>Hole Punch</td>
<td>Make the base of the hole punch wider</td>
<td>Make the hole punch holes smaller</td>
<td>Make the distance between the holes smaller</td>
</tr>
<tr>
<td>Mobile Phone</td>
<td>Make the mobile phone wider</td>
<td>Make the button height smaller</td>
<td>Make the screen wider</td>
</tr>
<tr>
<td>Stapler</td>
<td>Make the base of the stapler larger</td>
<td>Make the staple holder smaller</td>
<td>Make the hinge bar larger</td>
</tr>
</tbody>
</table>

Table 65: Key changes for each product for ‘Assignment One’

These changes were tested on the models that the researcher had previously created and were timed, in order to make a judgement about whether the changes were of similar levels of difficulty. These can be seen in Table 66. It was clear that all three aspects were easily changed and were clearly very similar changes, because the time taken to
change all three aspects across all four models only differed by only 30 seconds [refer to Figure 58].

Therefore a redesign exercise was generated, where each participant was asked to make three key design changes to their models.

<table>
<thead>
<tr>
<th>Product</th>
<th>Before Changes</th>
<th>After Changes</th>
<th>Time Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculator</td>
<td><img src="image1" alt="Calculator Before" /></td>
<td><img src="image2" alt="Calculator After" /></td>
<td>136 seconds</td>
</tr>
<tr>
<td>Hole punch</td>
<td><img src="image3" alt="Hole Punch Before" /></td>
<td><img src="image4" alt="Hole Punch After" /></td>
<td>113 seconds</td>
</tr>
<tr>
<td>Mobile phone</td>
<td><img src="image5" alt="Mobile Phone Before" /></td>
<td><img src="image6" alt="Mobile Phone After" /></td>
<td>142 seconds</td>
</tr>
<tr>
<td>Stapler</td>
<td><img src="image7" alt="Stapler Before" /></td>
<td><img src="image8" alt="Stapler After" /></td>
<td>143 seconds</td>
</tr>
</tbody>
</table>

Table 66: Redesigning the models - Researcher timings for all three changes
Data collection method

All of the participants were invited to an evaluation session, where they were asked to use the CAD model that they submitted and make key design changes to it. Three ‘pairs’ volunteered for the evaluation session (P902A, P902B, P903A, P903B, P907A and P907B). The method of direct overt participant observation [Dawson 2006:149-151, Bell 2005, McNiff et al. 2003, refer to Chapter Three, section 3.3.2] was used to record how long the participant took to make each design change, as can be seen in Figure 59.

Figure 58: Time taken for researcher to make the three specified design changes
Figure 59: Example of direct overt participant observation [Dawson 2006, Bell 2005, McNiff et al. 2003] used in Main Study [P902B]

Data analysis method

The times taken for the participants to make each design change were recorded.

Results

The results show that the participants within the CMS Group made their design changes in a total of 1188 seconds, whereas the Control Group made the changes in a total of 3864 seconds [refer to Table 67 and Figure 60]. This showed that the CMS Group were able to make the key design changes in half the time of the Control Group.
<table>
<thead>
<tr>
<th>CMS Group score</th>
<th>Control Group score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant</td>
<td>Time taken to make</td>
</tr>
<tr>
<td></td>
<td>all three design</td>
</tr>
<tr>
<td></td>
<td>changes (s)</td>
</tr>
<tr>
<td>P902A</td>
<td>291</td>
</tr>
<tr>
<td></td>
<td>(116 +131+44)</td>
</tr>
<tr>
<td>P903A</td>
<td>568</td>
</tr>
<tr>
<td></td>
<td>(279+168+121)</td>
</tr>
<tr>
<td>P907A</td>
<td>329</td>
</tr>
<tr>
<td></td>
<td>(57+177+95)</td>
</tr>
<tr>
<td>P902B</td>
<td>920</td>
</tr>
<tr>
<td></td>
<td>(578+172+170)</td>
</tr>
<tr>
<td>P903B</td>
<td>1513</td>
</tr>
<tr>
<td></td>
<td>(958+247+308)</td>
</tr>
<tr>
<td>P907B</td>
<td>1431</td>
</tr>
<tr>
<td></td>
<td>(1020+187+224)</td>
</tr>
</tbody>
</table>

Table 67: Results of the redesign exercise

Figure 60: Time taken to make three key design changes per participant

---

20 P907B could not make change – data denotes time at which P907B moved on to the second change
Summary: Specific research question three

- The three participants within the CMS Group were able to make key design changes to their model in half the time of the Control Group.

9.5.5 Specific research question four, five and six

Did the CMS Group feel that the CMSS material had helped them? What was good about the material? What could be improved?

Research methods

It was decided to use both qualitative and quantitative methods for this element of the evaluation through the use of both questionnaires and interviews. It was necessary to discover how the participants in the research reacted to the CMSS material, conforming to Level 1 (‘Reaction’) of Kirkpatrick’s levels of evaluation [1998]. Additionally it was interesting to consider whether the learners’ attitudes and behaviour when modelling on CAD had changed, conforming to Levels 2 (‘Learning’) and 3 (‘Behaviour’) of Kirkpatrick’s levels of evaluation [1998].

The participants in the CMS Group also completed a questionnaire regarding the CMSS material [refer to Appendix 3]. This covered a number of questions/statements including:

- How helpful did you find the CMSS material?
- Was the content of the material clear?
- Would you recommend this to other students learning Pro/ENGINEER?
- Do you think it is important to teach this content?
- Has this made you think differently about the way you will model products on CAD?
- Did you have any problems with any of the material?
- Please list some of the ways the resource could be improved
- Please list any suggestions for content that should be added
Additional comments

The interview covered the following questions:

- Do you feel that you are a confident CAD modeller having used this material?
- Do you feel that this material has helped you to use Pro/ENGINEER for designing products?
- Will you be using the strategies that you have learnt in future projects?
- Did you have any problems with the material?
- Do you have any suggestions for content that could be added?

Some of the open answers in the questionnaire were repeated in the interview, because it was noted that in some cases, participants feel more comfortable talking than writing about a topic and vice versa.

Data collection method

The results of the questionnaire were entered into Microsoft Excel for analysis. The interviews were transcribed. An example of an interview transcription can be seen in Appendix 4.

Data analysis method

Microsoft Excel was used to generate visual representations of the results of the questionnaire. The interviews were coded and clustered [Miles & Huberman 1984 - refer to Appendix 4].

Results

The results section has been split into two sections, to distinguish between the results that were collected from the questionnaire data and those that were collected from the interviews.

The participants were asked, in the questionnaire, how helpful they found the CMSS material and the results were very positive. The majority of the participants felt that the CMSS material was either helpful or very helpful [refer to Figure 61].
The participants were then asked whether they felt that the content of the material was clear, where eight out of ten participants noted that it was. This was encouraging as the ‘content’ of the material ranged from step-by-step exercises through to the content that was on the Internet [refer to Figure 62].
When asked whether the participants would recommend this to other students learning to use Pro/ENGINEER, 100% of the participants that responded said ‘yes’ [refer to Figure 63].

Figure 62: Results of ‘Evaluation Questionnaire 1’ Question 1.2 ‘Was the content of the material clear?’

Figure 63: Results of ‘Evaluation Questionnaire 1’ Question 1.3 ‘Would you recommend this to other students learning to use Pro/ENGINEER?’
The participants were also asked whether they thought that it was important to teach this content, where seven participants said ‘yes’ [refer to Figure 64].

![Figure 64: Results of ‘Evaluation Questionnaire 1’ Question 1.4 ‘Do you think that it is important to teach this content?’](image)

The participants were then asked whether the research had made them think differently about the way they will model products on CAD and nine out of ten said that it had [refer to Figure 65].
Additionally, the participants were asked whether they had any problems with any of the material. Five participants made comments regarding problems that they had experienced [refer to Table 68].

<table>
<thead>
<tr>
<th>Comments relating to problems experienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>I do find Pro/ENGINEER very hard to grasp even with support material, but once I used it repetitively it was very helpful [P903A]</td>
</tr>
<tr>
<td>Too much writing could be animated [P904A].</td>
</tr>
<tr>
<td>Some of the understanding of the strategy and applying it to the model [P905A].</td>
</tr>
<tr>
<td>Copy geometry – couldn’t get screen to work as 3D form [P908A].</td>
</tr>
<tr>
<td>Yes, some of the complex features I found hard to grasp; such as reference/reference geometry [P911A]</td>
</tr>
</tbody>
</table>

Table 68: Comments relating to problems the participants had experienced with the material

A number of open questions [Dawson 2006:90] were given to the participants, to generate more feedback about how to improve the CMSS material. The participants
were asked to list some of the ways that the CMSS material could be improved. The results can be seen in Table 69:

<table>
<thead>
<tr>
<th>Comments relating to how the material can be improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step-by-step guide possibly, showing pictures as you go [P902A]</td>
</tr>
<tr>
<td>A quick help menu for the basics [P903A]</td>
</tr>
<tr>
<td>Could be animated and voice talk through [P904A]</td>
</tr>
<tr>
<td>How to apply the strategy to the model [P905A]</td>
</tr>
</tbody>
</table>

**Table 69: Suggestions relating to how the material can be improved**

The participants were then asked to list suggestions for content to be added, as can be seen in Table 70.

<table>
<thead>
<tr>
<th>Comments made relating to content to be added</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perhaps going over all the features and linking them to the product to make sure we are not marked down for missing features [P901A]</td>
</tr>
<tr>
<td>Possibly reasons why parts don’t work or why the layout of the program is such [P909A]</td>
</tr>
<tr>
<td>How to animate (explode + move around) models would be useful to learn and interesting to see included [P911A]</td>
</tr>
</tbody>
</table>

**Table 70: Comments made relating to content to be added**

A number of participants also made additional comments on the questionnaire, which can be seen in Table 71.
### Additional comments

<table>
<thead>
<tr>
<th>Ref. Geometry helpful [P901A].</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very well demonstrated &amp; useful for improving on CAD [P902A].</td>
</tr>
<tr>
<td>I do think that when the degree is started a lot of people were thrown into using Pro Engineer with little/no knowledge of the program. I especially found it hard so having this kind of resource is very helpful [P903A].</td>
</tr>
<tr>
<td>Generally found was very helpful &amp; put across in a way I could understand [P909A].</td>
</tr>
<tr>
<td>Thanks for the help! [P911A]</td>
</tr>
</tbody>
</table>

**Table 71: Additional comments**

With regard to the interviews with the participants of the CMS Group, several positive aspects were noted:

- **The CMSS material had helped the participants to use Pro/ENGINEER**
  All participants in the CMS Group that were interviewed said that the CMSS material had helped them to use Pro/ENGINEER. The comments relating to this can be seen in Table 72.
<table>
<thead>
<tr>
<th>Participant number</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P901A, 12</td>
<td>Yeah it has helped, it has helped with the, as I said the copy geometry and the reference geometry because then the parts all change automatically</td>
</tr>
<tr>
<td>P902A, 20</td>
<td>… It was a lot easier than I actually anticipated it to be</td>
</tr>
<tr>
<td>P902A, 28</td>
<td>Yeah I think it has definitely erm it’s just really helped me in lots of places when you think about a product and then when I put it into CAD what I do first and how I do it as well because otherwise it just goes wrong</td>
</tr>
<tr>
<td>P903A, 8</td>
<td>Yeah it’s good to come back to as well</td>
</tr>
<tr>
<td>P903A, 28</td>
<td>…we hadn’t been taught any sort of computer programs at school whatsoever and so when we came here it was really difficult and I find it quite, just it didn’t click, but this helps with that</td>
</tr>
<tr>
<td>P904A, 6</td>
<td>…it gives you me more erm greater understanding of how to use the program</td>
</tr>
<tr>
<td>P905A, 45</td>
<td>Yeah it has made me you know erm just explore the program a bit</td>
</tr>
<tr>
<td>P907A, 36-38</td>
<td>…But I think that actual thing is really helpful and like definitely more helpful than say what we’ve been given like our lessons and like we’ve been given some COAch something and that wasn’t and I didn’t find that particularly helpful… but I’m finding yours more helpful</td>
</tr>
<tr>
<td>P908A, 12-14</td>
<td>… I thought it was very well laid out as well because like with the screen shots and that… it helped quite a lot…</td>
</tr>
<tr>
<td>P908A 83 – 86</td>
<td>…just I did find it really helpful… so yeah it was good</td>
</tr>
<tr>
<td>P909A, 7-10</td>
<td>Definitely yeah… I’d be completely lost without it…</td>
</tr>
<tr>
<td>P9011A, 14</td>
<td>…it’s given me a different view how to do it which I find easier than other methods that I’ve been taught so yes</td>
</tr>
<tr>
<td>P911A, 66</td>
<td>… it’s been really helpful and useful – thank you very much for helping</td>
</tr>
</tbody>
</table>

Table 72: Feedback from participants regarding the CMSS material

- **The presentation of the material was clear**
  It was also felt that the material was clear because it was web-based [P901A]. Another participant also noted that they found the material helpful and well laid out [P908A].

- **The material made CAD easier to understand**
  One participant also noted that it made CAD easier to understand than going through step-by-step guides [P902A], possibly because it does not rely entirely on a click-by-click approach.
A number of the participants felt that they were confident or more confident CAD modellers

A number of participants suggested that they felt they were a confident or more confident CAD modeller having used the material [P904A, P907A, P909A, P911A].

Having used the material I feel more confident than I would have without using it because it gives er what felt like a better strategy for erm designing my model around other than just trying to assemble all the parts once I made them all.

P911A

P903A suggested that although they wouldn’t say that they were ‘confident’, they did think the material had helped them, and P908A said that they felt ‘in between’ and that although they could use CAD comfortably, there were still some things that needed some practice. Four participants noted that they did not feel that they were confident CAD modellers (P901A, P902A, P905A and P906A).

The participants would use strategies in future projects

Six participants said that they would use the strategies that they had learnt in the future [P901A, P903A, P904A, P906A, P907A, P911A], two of which said that they were using it on their new CAD assignment. Four participants said that they would use some of the strategies that they learnt in future [P902A, P905A, P908A, P909A].

Problems noted with the CMSS material

During the interviews, some problems with the CMSS material were noted, as detailed below.

The participants’ inexperience at using Pro/ENGINEER restricted them

P905A mentioned that they needed more of a general understanding of what the strategies were because they felt inexperienced at using Pro/ENGINEER and felt that they needed more instruction from generating the strategy to applying it to
the model [P905A]. P906A also mentioned that it was difficult applying the copy geometry, but that in the future (having become more familiar with Pro/ENGINEER), they would be able to use it [P906A].

- **The material was implemented too early in their CAD education**
  Two participants said that the material had been implemented too early in their CAD education [P905A, P906A] and that some participants found the material problematic because they had not used all of the features at the time of using the material [P905A, P906A]. Again, one participant found that they didn’t have any knowledge of the features for the assignment [P906A].

- **Some aspects of the ‘strategies’ were difficult to grasp**
  P906A mentioned that they could grasp the copy geometry strategy, but could not grasp the others. They also noted that they could not fully grasp the assembly guide [P906A]. One participant found the copy geometry difficult because they had not used any of the settings before [P908A].

- **Some of the exercises were not clear**
  The exercises were not clear in terms of what order they were in [P909A]. One participant found the exercises confusing because there were lots of ways that a particular ‘task’ could be completed and the participant sometimes got ‘lost’ [P909A]. P904A suggested that there was too much writing on the exercises and that they were not very clear and easy to follow [P904A].

<table>
<thead>
<tr>
<th><strong>Summary: Specific research question four, five and six</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- All participants in the CMS Group that were interviewed said that the CMSS material had helped them to use Pro/ENGINEER and the majority of the participants felt that the CMSS material was either helpful or very helpful.</td>
</tr>
<tr>
<td>- When asked whether the participants would recommend this to other students learning Pro/ENGINEER, 100% of the participants that responded said ‘yes’.</td>
</tr>
<tr>
<td>- Nine of the participants noted that the material had made them think differently about the way they would model on CAD.</td>
</tr>
</tbody>
</table>
• Typical problems with the material included there being too much textural content contained within the material, not fully understanding how to apply the ‘strategy output’ to the CAD model and with regard to applying the more advanced copy geometry strategies.

• In terms of how the CMSS material can be improved, comments included adding step-by-step guides (with images), a quick help menu, animations and more information regarding applying the ‘strategy output’ to the CAD model.

• With relation to content to be added, suggestions included additional material that explains how to ‘recover’ the model when an error message appears and adding an ‘incentive tutorial’ to ‘hook’ the learners in.

• Negative feedback included that four of the participants did not feel that they were confident CAD modellers having used the material, some of the participants suggested that their inexperience at using Pro/ENGINEER restricted them and that perhaps the material had been implemented too ‘early’ in their CAD education. Some of the participants found that some of the ‘strategies’ were difficult to grasp and some of the exercises were not clear enough.

• Selective positive comments include that the CMSS material was ‘...useful for improving on CAD’ [P902A], ‘Generally found [that the CMSS material] was very helpful and put across in a way I could understand’ [P909A], ‘...it was a lot easier than I actually anticipated it to be’ [P902A], ‘... it’s good to come back to as well’ [P903A], ‘it’s been really helpful and useful – thank you very much for helping’ [P911A] and ‘...I’d be completely lost without it’ [P909A].

This feedback provided useful information relating to what content should be added in the next iteration of the material, as can be seen in Table 73.
<table>
<thead>
<tr>
<th>Content to be Added</th>
<th>Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>More information on why it is better to use one feature over another</td>
<td>P901A</td>
</tr>
<tr>
<td>More information on how to use the basic features</td>
<td>P901A, P904A</td>
</tr>
<tr>
<td>More information on how to resolve error messages</td>
<td>P901A, P907A</td>
</tr>
<tr>
<td>More step-by-step guides</td>
<td>P902A</td>
</tr>
<tr>
<td>Screen shots of where each feature is to save navigating around Pro/ENGINEER</td>
<td>P902A</td>
</tr>
<tr>
<td>A quick refresh screen so that you can get back ‘into’ CAD after a break</td>
<td>P903A</td>
</tr>
<tr>
<td>A quick help menu, so that you can quickly access a basic step-by-step guide and</td>
<td>P903A</td>
</tr>
<tr>
<td>search for things, similar to a Windows-based help system</td>
<td></td>
</tr>
<tr>
<td>Animations/videos showing how each feature is created</td>
<td>P904A</td>
</tr>
<tr>
<td>A large model tree that shows you every feature, so that you can access information</td>
<td>P904A</td>
</tr>
<tr>
<td>about the different strategies that could be used</td>
<td></td>
</tr>
<tr>
<td>An interactive section where you can pick on a curved surface, for example and it</td>
<td>P904A</td>
</tr>
<tr>
<td>would tell you what features you could use, leading to a tutorial</td>
<td></td>
</tr>
<tr>
<td>Database of specific features and information to show you how to create them</td>
<td>P904A</td>
</tr>
<tr>
<td>Clearer instructions about how to create a well constrained assembly</td>
<td>P906A</td>
</tr>
<tr>
<td>More screen shots of menus</td>
<td>P909A</td>
</tr>
<tr>
<td>More information about how you go about using different parts of the software</td>
<td>P909A</td>
</tr>
<tr>
<td>Flashy ‘incentive’ tutorial from concept generation to rendering to ‘hook’ users</td>
<td>P911A</td>
</tr>
<tr>
<td>in</td>
<td></td>
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</tbody>
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Table 73: Content to be added

9.6 Summary

From an early stage, the literature and experimental research pointed at a definition of a good CMS:

*Using the most effective features to create an accurate CAD model of a design/concept, allowing key design changes to be implemented quickly and efficiently.*

[Refer to Chapter Two section 2.2]

The implementation of the CMSS material and the subsequent evaluation of the material related directly to the specific research objectives set out for each part of the
research. The aim of the evaluation was to establish whether the use of the CMSS material produced a more competent CAD user who could easily make design changes to their models. The evaluation of the CMSS material was implemented through the use of questionnaires, interviews and CAD model analysis. The strategy used for evaluating the CMSS material was outlined and key issues relating to the accuracy of the evaluation discussed. The culmination of these results indicated that the CMSS material produced a more competent CAD user who could create an accurate CAD model and make design changes quickly and effectively, as discussed further in Chapter Ten.
10 DISCUSSION

Overview: The results of the main study are discussed further in this chapter.

10.1 Introduction
The notion of instructing product designers to use CAD on a strategic level was found to be a key area for improvement. Specifically, the area that was felt to be lacking was communicating effective strategies to novice CAD users, in order to become more competent CAD users who could redesign their CAD models quickly and effectively. This issue was addressed through the development of the CMSS material, which acted as a strategic experiential learning resource, guiding the user to employ effective CMS, as well as acting as a reference resource for use at later stages of their CAD education and careers.

10.2 Benchmarks and indicators
As a result of the ‘Exploratory Study’, it was proposed that there were three distinct knowledge areas that the user needed to be aware of in relation to the selection of an effective CMS (‘feature-based’ approach, ‘detailed’ approach and ‘overarching’ approach), but it was clear that there was no resource available that combined all three aspects. The CMSS material was designed to support existing CAD teaching material that covered the ‘feature-based’ approach, and provided the learner with guidance on the ‘detailed’ approach and ‘overarching’ approach, thus providing them with the knowledge required to select an effective CMS. It was proposed that through the use of this material, that effective CMS could be taught to novice CAD users, which would enable them to capture their design intent effectively, whilst being able to make key design changes to their model. It was supposed that if such material were developed, many of the disadvantages noted previously in Table 1 could be negated, as detailed in
Table 21. It was also envisaged that at the end of the ‘learning process’, the learner would have a number of key learning ‘traits’ as detailed in Figure 19.

10.3 CMSS material
The CMSS material was formed of a combination of four distinct communication approaches including web-based material, printed material, group work and tutorials. This blended approach was used to ensure that all of Kolb’s learning styles [1984, Kolb et al. 2000] were allowed for. The web-based material was considered to be the core of the CMSS material and incorporated three sections including the ‘Previous Material’ section, ‘The Strategy’ section (containing the main strategic element of the CMSS material) and the ‘Support Material’ section.

The CMSS material encouraged the learner to think about the aspects, identified previously in Chapter Five, that were necessary in order to select an effective CMS. Having answered some initial questions, they were presented with one of three strategies:

- ‘Trial and error’ strategy [refer to Chapter Five, section 5.2.1]
- ‘Sharing’ strategy [refer to Chapter Five, section 5.2.2]
- ‘Separate’ strategy [refer to Chapter Five, section 5.2.3]

It was envisaged that the majority of product designers would use the ‘sharing’ strategy, which involved elements of both the ‘overarching’ approach and the ‘detailed’ approach. In order to use this section of the CMSS material, the learner was required to know how many parts there were in their model and whether any of the parts needed to share geometry. The learner was initially presented with an overview of the information and was able to view more detailed information as necessary conforming to the three tiered level approach to presenting information [refer to Chapter Six]. The learner could then move onto the strategic section of the CMSS material (the ‘detailed’ approach). The learner was asked a number of key questions regarding the product that they were modelling and was then presented with a CMS output, which provided them with a step-by-step guide to modelling the product.
With regard to CAD modelling support, the learners had access to support material (including an interactive section, help section and database of common forms) and had access to five presentation boards [refer to Chapter Two, section 2.4.2]. They were also given two presentations about CMS, printed copies of the example exercises, printed copies of access instructions for the web-based material and had the option to attend weekly support sessions.

10.4 Results

A number of approaches were used to establish the level of success of the CMSS material, which are detailed in Chapter Nine. The first stage of the evaluation involved ensuring that all participants in the CMS Group had created realistic looking models. This was possible by accessing the final marks for ‘Assignment One’, as the participants had to create a realistic model in order to pass the assignment. This was ideal, as the assignments were marked independently, which negated any researcher bias. All of the participants in the CMS Group had passed the assignment, and had therefore created realistic looking models.

The next stage of the evaluation involved undertaking a rigorous analysis of the CAD models, to establish whether the participants in the CMS Group had implemented any of the CMS. This was necessary in order to ensure that the assumptions made were valid. For example, if any of the participants did not appear to have implemented any of the strategies detailed within the CMSS material, it would not be valid to draw conclusions relating to the CMSS material, based on their results. Having analysed the CAD models, it appeared that all participants in the CMS Group had implemented at least one of the strategies presented to them, as expected, through the use of the CMSS material and the introductory session. A check list of key strategies was used to draw this conclusion, whereby if the participant within the CMS Group had used one of the five strategies identified [refer to Chapter Nine, section 9.5.2], it was assumed that they had applied the knowledge from the CMSS material. In this example, all of the participants from the CMS Group were deemed valid to be included in the results.

It was then necessary to establish whether using the CMSS material had led the participants to use a more effective CMS than the Control Group. From this we would
assume that, theoretically, they would be able to make design changes quickly and effectively. In order to make a judgement on the participants’ strategy, the researcher applied a score to the model, either 1, 2 or 3, depending on the effectiveness of the CMS used. For example, a score of 1 indicated that the participant had used a ‘poor’ strategy, and a score of 3 indicated that they had used a ‘good’ strategy. Obviously, some parts were extremely simple, and it would not have been appropriate to assign the part a score, in which case the part was removed from the analysis. An example of such a part was a mobile phone screen, which had simply been created using an extruded rectangle. This ensured that a judgement was made only on those parts that involved a choice of strategy. The researcher analysed all of the models, complied them and then asked two ‘practiced’ CAD users to assign a score to the part, using the same criteria. This was necessary in order to verify the scores that the researcher had given. As expected, the number of parts that each group had created differed – the CMS Group had produced 65 valid parts and the Control Group had produced 62 valid parts. Therefore, it was necessary to calculate the maximum score that each group could have achieved (total number of parts per group multiplied by the maximum score) and use this to calculate the group score as a percentage. The analysis showed that, having had access to the material, the CMS Group had generally used a more effective strategy than the Control Group. Theoretically, the material was a success, as it showed that the CMS Group had not only used the CMSS material but had also applied it to their CAD modelling task. However, on looking more closely at the individual parts, it was clear that three of the participants within the CMS Group had used considerably less effective strategies than the Control Group, as can be seen below in Figure 66.
On looking further into this data, it was clear that P910A and P911A had attempted to create considerably more parts than P910B and P911B respectively, which may indicate that the CMS Group felt more confident at tackling more complicated assembly models than the Control Group. Also worthy of note when considering P908A’s parts versus P908B’s parts was that three of P908B’s parts were not included in the analysis as they were too simple, whereas all of P908A’s parts were included [refer to Appendix 10]. Another element that may have resulted in some of the participants using a less effective strategy is their usage of the CMSS material. P910A and P911A had shown relatively low usage of the material, which may indicate that significant usage of the CMSS material is required for some participants in order to fully understand and apply their CMS effectively.

Theoretically, the participants who used a more effective CMS than the Control Group should have been able to redesign their CAD models more quickly and effectively in comparison to the Control Group. In order to test this theory, a redesign exercise was generated [refer to Chapter Nine, section 9.5.4 for details of the exercise], whereby six participants (three from the CMS Group and their corresponding pair within the Control
Group) were asked to redesign three aspects of the models that they submitted for ‘Assignment One’. This was necessary to not only establish whether the CMS Group could make design changes quickly and effectively, but also to understand how they performed in comparison to their pair within the Control Group. Direct overt participant observation [Dawson 2006, Bell 2005, McNiff et al. 2003] was used to log the CAD modelling exercise, to ensure that the timings were accurate.

The results showed that the three participants in the CMS Group were able to make key design changes to their model effectively. In fact, when compared to their pairs in the Control Group, it was found that the CMS Group participants could make changes in almost half the time. This was extremely encouraging, as it confirmed that having used and applied the information from the CMSS material, they could easily make the changes requested.

The results noted above were necessary to establish whether the content of the CMSS material had helped the participants to model more effectively on CAD. The second phase of the evaluation was undertaken to gain feedback on the material and how the information was communicated.

As noted previously, both qualitative and quantitative methods were used within this part of the evaluation. A questionnaire was designed which allowed the researcher to discover whether the participant thought the material was helpful, whether it was clear for them to use and crucially, whether they would recommend the material to their peers. Additionally, it was important to establish whether they felt that they were a ‘confident’ CAD modeller having used the material, whether they thought that it was necessary to teach the material and whether it had made them think differently about modelling on CAD, which would provide a good indication of the influence of the material on the learners. It was also necessary to provide the participants with an opportunity to detail any problems that they had with the material, and improvements that could be made. Questions requiring longer answers were repeated in an interview, as it was noted that participants sometimes felt more comfortable verbalising their response rather than writing it, and vice versa.
When asked whether the participants felt that the material was clear, eight out of ten participants said that it was, which suggests that a blended approach to communicating the material was effective, especially as it appealed to all of Kolb’s [1984, Kolb et al. 2000] leaning styles. By using a mixture of click-by-click and high-level CAD instruction, it ensured that participants did not get ‘stuck’ on the detail within a CAD exercise, which could stop learners from moving forward. Encouragingly, when asked whether the participants would recommend the material to other students learning to use Pro/ENGINEER, all of the participants that responded said that they would. Seven participants believed that it was important to teach the content, and the remaining three participants selected ‘no feeling’. It may be interesting to undertake further investigation to establish why these participants did not select ‘yes’ or ‘no’. With regard to how the participants felt about modelling on CAD, it was found that nine out of ten participants thought that they were now thinking differently.

The participants were also asked about specific problems that they experienced with the CMSS trial. It was found that the responses generally related to the complexity and functionality of the Pro/ENGINEER modelling system, and the participant’s inexperience in terms of using the basic features.

With regard to the complexity of the Pro/ENGINEER system, P903A noted that Pro/ENGINEER was hard to grasp at first, but suggested that having used it again, it was more ‘helpful’. This suggests that with practice, even a relatively complex software package, such as Pro/ENGINEER, can become easier for a novice CAD user to understand. Again, P911A found the seemingly ‘complex’ features hard to grasp, but this may have been due to the relatively short amount of time they spent using the online CMSS material. Three participants mentioned that some of the strategies were difficult to grasp (P905A, P906A and P908A), which could relate to the concept of the strategies (for example, how a sketch can be shared between two parts), or simply the practicality of sharing a sketch (for example, where the features are on the CAD system). P908A had a problem with the copy geometry on the ‘screen’ part, although this was related to a problem with the CAD system rather than the CMSS material.
Additionally, two of the participants (P905A, P906A) noted that their inexperience of using Pro/ENGINEER restricted them. Unfortunately, these participants had not used all of the basic features previously, which again, reinforces that assumption that it is fundamental that all participants can use the basic features before they use the CMSS material. The same participants mentioned that the material was implemented too early in their CAD education. Again, as they had not used all of the basic features before, it is not surprising that they felt that the material was less successful for them. The application of the strategy to the model was found to be another problematic element of the CMSS material, although again, P905A had not used all of the features before using the CMSS material so it was understandable that applying the strategy to the model was problematic.

The participants were also asked about their confidence at using Pro/ENGINEER as a result of having used the CMSS material. In general terms, four participants said that they were confident or more confident CAD modellers having used the material (P904A, P07A, P909A and P911A), P903A suggested that although they would not say that they were ‘confident’, they did think the material had helped them, and P908A said that they felt ‘in between’ and that although they could use CAD comfortably, there are still some things that needed some practice. This was extremely encouraging, having only received one term of CAD tuition. Four participants noted that they did not feel that they were confident CAD modellers (P901A, P902A, P905A and P906A). However, P906A and P905A stated that they could not use all of the basic features before they started using the material (perhaps because they had missed a lecture), which confirms the emergent theory from the Exploratory Study [Chapter Two, section 2.6], that the participants must be able to use all of the basic features before they use the CMSS material. With regard to P902A, they appeared to be extremely competent at using Pro/ENGINEER, having created a realistic looking model and been able to make design changes extremely quickly. Also, P901A had used a considerably better strategy than their pair in the Control Group and had used the CMSS material significantly, so it may be interesting therefore, to investigate their negative feelings towards their confidence.
Another element of the evaluation was to establish whether the participants believed that the CMSS material had helped them. The questionnaire data showed that the majority of the participants found the CMSS material either ‘helpful’ or ‘very helpful’ (those participants who did not select ‘helpful’ or ‘very helpful’ either did not respond, or selected ‘no feeling’). When asked the same question in the interview, the participants also made several positive comments relating to the material, especially when exploiting the parametric nature of the software, where ‘…the parts all change automatically’ [P901A]. P901A noted that they found it easier than they anticipated it to be, which shows that the prospect of creating a model using an efficient and effective strategy can be daunting to novice CAD users, but at the same time, entirely achievable. P902A found that having a plan that showed them how to approach building the model was useful and P908A suggested that the material was well presented, for example, with regard to the screen prints. P903A suggested that the material was good to ‘…come back to’, which is positive, considering that if implemented within a university environment, the learners would often take long breaks for university holidays and they may not have the opportunity to apply the CAD knowledge until they returned. P903A also mentioned their lack of computer experience at school prior to embarking on the course and suggested that the CMSS material helped them at university.

In terms of using Pro/ENGINEER generally, P904A said that it gave them a greater understanding of how to use the program and P905A suggested that it had helped them to explore the program more. P911A suggested that it had given them different views with regard to modelling, which are easier than other [feature-based] methods. P907A compared the CMSS material to Pro/ENGINEER COAch, and suggested that the CMSS material was more helpful. Some of the participants also made a number of other positive comments - P908A said that the material was ‘…really helpful’, P911A said it’s been ‘…really helpful and useful’ and P909A even suggested that they’d be ‘…completely lost without it’.

The additional comments section provided an interesting and unprompted notion of the participants’ perception of the CMSS material, where all of the comments were very positive, particularly as one participant [P903A] found CAD hard and thought that the material was helpful. Other comments related to it having been ‘…put across in a way I
could understand’ [P909A], that ‘…this kind of resource is very helpful’ [P903A], that the reference geometry was useful [P901A], and that the content was ‘…very well demonstrated and useful for improving on CAD’ [P902A].

When asked whether they would use the strategies again in future projects, all of the participants that were interviewed said that they would use at least some of the strategies in future projects, and two of the participants said that they were using the CMSS material for their new CAD assignment, which again, was very positive.

A number of suggestions were made by the participants that related to improving the material.

It was suggested that expanding the ‘detailed’ approach section of the CMSS material to include more information on the pros and cons of using one feature over another would improve the material. This explanatory information would appeal to ‘Theorists’ [Honey & Mumford 1982] who may wish to understand the rationale behind the suggestions made within ‘The Strategy’ section. This information could be included as an additional column on ‘The Strategy’ print out, which could also include information relating to how much time a model is likely to take to create. This would allow for time allocation at the planning stage of the design project.

Interestingly, a number of suggestions were made that referred specifically to the ‘feature-based’ approach, which, although were deemed outside the scope of this research, may be necessary to elaborate on in a future iteration of the CMSS material. These included adding more information relating to how to use the basic features and how to use the copy geometry settings. It was also found to be necessary to include clearer instructions on how to resolve error messages and how to create a well constrained assembly, which again, would typically be included in a ‘feature-based’ software specific learning resource. Although this was covered in the support tutorials, it may be necessary to incorporate it within the written material, to act as a reference for the learner.
The inclusion of a help feature, denoting where each feature is on the GUI using screen prints was also suggested. This would save the learners searching for the features, thus saving them time. This also links to the notion of a ‘quick refresh’ screen to help the learners (particularly in higher education) use CAD again after a break, such as a university holiday. Another comment related to the use of a ‘quick help menu’, which would present the key support information in an easy to access format, similar to a Windows help system. This would be particularly useful to those learners who need a quick solution to their problem, and could direct the learner straight to the ‘Level 3’ information (refer to Table 42 ‘Making a complex system comprehensible’ [Fischer 1991:17]).

With regard to making the material easier to use, one suggestion was to incorporate more step-by-step guides to appeal specifically to Kolb’s [Kolb et al. 2000] ‘Converging’ learning style, coupled with images to illustrate the key points. P909A noted that the CAD exercises were not clear, which can be easily rectified in the next iteration of the material. Example CAD models could be included, so that the learner could examine the strategy that has been used across various products. For example, an interactive CAD model could be included that allows the learner to pick one aspect of the model and then be directed to a tutorial relating to the strategy that has been used and how to replicate it. With regard to showing the user how each feature within a particular model was created, it was suggested that animations might be useful, especially when working remotely. Learnings could be taken from Stevenson [1995], who describes a system whereby novice CAD users are shown the basics of using an (architectural) CAD system using animations. This would add an interactive element to the CMSS material, which would appeal to visual learners and could contain spoken explanations, much like a lecture or lesson. However, when using more interactive elements, such as animations, care must be taken to ensure that the learners can access the information quickly online. The developer could refer to a standard minimum specification for computers and optimise the images or animations used, allowing them to be downloaded quickly.

Another improvement to the CMSS material would be to include a motivational ‘incentive’ tutorial [refer to Chapter Seven, section 7.3.1] that would take the user from
concept generation through to rendering to motivate the learners. This was attempted within this research, although it did not incorporate rendering. It is believed that it is necessary to include rendering in the incentive tutorial, as this appeals to novice CAD users and could help to motivate them to use CAD effectively. Another suggestion for content to be added was how to animate the models that had been created, similar to the incentive tutorial in the CAD/CAM Achiever.

As described previously, a funding bid was put forward (which was successful), for the CMSS material to be developed through the Engineering Centre for Excellence in Teaching and Learning (engCETL). This is currently in progress and it would be very interesting to establish what effect this resource has on novice CAD users. A ‘before and after’ study [Kumar 1996] could again be used to compare those participants exposed to the material with those who were not.

10.5 Summary

To summarise, it was found that when used significantly, the CMSS material was a success, having allowed designers to create realistic looking models using an effective strategy. It was found, on further investigation, that using an effective strategy allowed a number of the participants in the CMS Group to make key design changes to their model quickly and effectively, when compared to their pairs in the Control Group. In fact, the participants in the CMS Group could make their changes in half the time of the Control Group.

Although the ‘feature-based’ approach clearly remain a fundamental aspect of CAD education, it is apparent that a combination of ‘overarching’ strategic guidance and ‘detailed’ approaches are becoming increasingly important. It is now necessary to discuss the implications of these findings in the wider context of CAD education and to draw conclusions of the research.
11 CONCLUSION AND FUTURE DIRECTIONS FOR RESEARCH

Overview: This chapter reviews the overall pedagogical implications of the research, with particular emphasis on the initial research objectives.

11.1 Introduction

The overall aim of this research was to develop effective CAD Modelling Strategies (CMS) and investigate the impact of these strategies on novice CAD users.

At the outset of the research, a highly structuralistic approach was taken to reviewing the prior art in the field and an emergent theme was noted in Chapter Two [section 2.6]. Individual aspects relating to learning to use CAD were explored and empirical evidence was collected. The emergent theme suggested that novice CAD users could be taught to use effective CMS through a combination of three distinct approaches; using all the basic features, using an ‘overarching’ approach and using a ‘detailed’ approach. It was then suggested that a number of disadvantages of using CAD could potentially be negated through the use of the CMSS material.

There is a general agreement that a competent CAD user can easily make modifications to their CAD model. This is especially relevant in a design consultancy/agency context, where design changes are often requested by the client at short notice. The CMSS material was developed and tested and it was apparent that the CMSS material could greatly improve a novice CAD modellers’ ability to create a model that could be easily modified and adapted. The evaluation of the CMSS material showed that the participants who had used the material had used a more effective strategy than the Control Group. For those examined in detail, this meant that they could make changes to their products in almost half the time of their pairs in the Control Group. Therefore, this chapter discusses these findings and their relevance within CAD education.
11.2 Exploring and defining ‘effective’ CMS

At the onset of the research, it was not clear whether ‘effective’ CMS had been defined previously, so a review of prior art was undertaken, using a review of literature and CAD teaching material.

The review of literature indicated that there were no clear guidelines in existence that aimed to communicate CAD to product designers on a strategic level. Although comprehensive, much of the literature was focused on how to use the features specifically. However, the literature suggested that there were two further approaches to modelling on CAD, which, although not defined fully, were later built upon for the CMSS material. These were termed as the ‘detailed’ approach and the ‘overarching’ approach. Additionally, Wiebe’s concept of ‘higher-level modelling strategies’ [2000, 2003] was useful as a basis for the research, as it suggested that CAD modelling skills can transfer between CAD packages.

The CAD resources that aimed to teach learners the basic CAD features were regarded as providing a ‘feature-based’ approach to teaching. These resources provided the learner with information and examples relating specifically to using CAD features. It was clear that many resources were available to novice CAD users that taught a ‘feature-based’ approach to modelling on CAD [e.g. Pro/ENGINEER COAch:2002, McMahon & Browne 1998, Rodriguez 1992], which can be termed as software specific and non-software specific resources. It was obvious that the CMSS material needed to complement and build upon such resources, to ensure that novice CAD users were able to use the basic features before they used the CMSS material.

The ‘detailed’ and ‘overarching’ approaches were positioned as the strategic aspects of the CMSS material and complemented each other as well as the ‘feature-based’ material. The ‘detailed’ approach provided specific details on how to model effectively on CAD, whereas the ‘overarching’ approach provided the learner with the ‘bigger picture’, giving them strategic advice on modelling the product as a whole. Useful information was collated from sources such as Alias StudioTools™ Art to Part’

Although the review of literature was useful in establishing a basis for the CMSS material, it was necessary to further investigate the emergent themes. This allowed empirical evidence to be collected, which focused heavily on the three themes noted above. Through the analysis of the ‘practiced’ CAD users’ models, it was confirmed that there was an element of selecting an effective ‘overarching’ and ‘detailed’ CMS when creating a CAD model. Case studies were used to examine various CAD models, where it was found that an obvious weakness of selecting an ineffective CMS was that it could result in a significant increase to the time it takes to model the part and the amount of features that are used. It was also interesting, when ‘practiced’ CAD users were questioned on a larger scale, to establish that an element of a ‘trial and error’ strategy was used. A group discussion also solidified this undercurrent of thought and the ‘trial and error’ strategy was therefore considered to be a formal CMS. Also, it was useful to confirm the use of other key strategies, such as the ‘symmetry’ strategy and the ‘skeleton’ strategy.

An emergent theme was then noted in Chapter Two [section 2.6], which was based on the previous findings and helped to define the remainder of the research. It was also possible to define the notion of ‘effective’ CMS through a combination of experimental research and a broad review of literature, which was used as a benchmark throughout the research:

*Using the most effective features to create an accurate CAD model of a design/concept, allowing key design changes to be implemented quickly and efficiently.*

[Refer to Chapter Two section 2.2]

Having defined ‘effective’ CMS, it was then necessary to consider how this could be further defined and compiled for use by novice CAD users.
11.3 Defining the content of the CMSS material

Two basic approaches were used to define the CMS content. The first was to detail and compile methods that contribute to using an effective CMS. It was also necessary to define the prerequisite knowledge that the learner would need in order to implement the CMSS material. The second was to establish what factors (apart from inexperience) affect the strategies that were chosen by relatively inexperienced CAD users. It was interesting to look at the subject of cognitive psychology, which gave the researcher an insight into how mental models are built and how three-dimensional forms are visualised. It was found that the novice CAD users had adopted different strategies to model the same part, as expected. However, through a group discussion, it was found that participants felt ‘forced’ to select a certain CMS and steps were therefore taken to counteract these issues and to enable the user to make an informed decision about which strategy to use, as detailed in Chapter Four. This resulted in a number of design considerations for the CMSS material:

1. Using CAD exercises that relate the product being modelled on CAD to a ‘real life’ example
2. Providing CAD exercises that show the user how to make use of shared geometry
3. Providing the learners with a formal planning process
4. Providing information relating to how to recover from error messages
5. Providing tutorials that show the user the potential to exploit an accurate CAD model, and how to make use of shared geometry
6. Providing examples of how to use features that are perceived as more ‘complicated’
7. Conveying the advantages of investing time creating an accurate CAD model that uses an effective CMS at the outset of the project
8. Providing support sessions. This is particularly important as learners can often become stuck on part of a feature and are unable to move forward with their modelling. By providing support in person, on email and via a discussion forum, it is possible to resolve many of the issues that CAD users find problematic. This also ensures that the learner does not feel isolated [Scanlon et al. 1987:264]
9. Ensuring that the material is aimed at all ‘types’ of CAD models, so as to provide all learners with the knowledge to model on CAD at a certain level

The specific content that was included in the CMSS material was defined in Chapter Five and included the following information:

- ‘Trial and error’ strategy for use when the learner does not have a clear idea of what they are creating
- ‘Sharing’ strategy (using ‘overarching’ and ‘detailed’ approaches) for use when the learner has a clear idea of what they are creating and requires the CAD model to link parametrically with other models
- ‘Separate’ strategy (using ‘detailed’ approaches) for use when the learner has a clear idea of what they are creating, but does not require the CAD model to link parametrically.

These strategies used a combination of ‘overarching’ approaches and ‘detailed’ approaches [refer to Chapter Two]. The ‘overarching’ approaches were defined as the ‘duplicate part’, ‘pattern’, ‘skeleton’ and ‘symmetry’ strategies [refer to Chapter Five]. The ‘detailed’ approaches were defined as the ‘pattern’, ‘profile-profile’, ‘reference-reference’, ‘revolve’, ‘sweep’ and ‘symmetry’ strategies [refer to Chapter Five].

It was also noted that there was some prerequisite knowledge that the learner must have in order to implement the CMSS material, which was defined as use of the following features/tools in Pro/ENGINEER and Pro/DESKTOP:

1. Sketcher
2. Blend/loft
3. Chamfer
4. Copy geometry
5. Draft
6. Extrude (protrusion/cut)
7. Hole
8. Pattern/array
9. Reference geometry
10. Revolve
11. Round
12. Shell
13. Sweep

11.4 Considering how the CMSS material should be presented to novice CAD users

The next logical step was to consider how to communicate this information to novice CAD users. Therefore, a review of literature on the broad subject of teaching and learning was undertaken.

It was found that there were many examples of good practice with regard to teaching CAD, which stem primarily from the National Curriculum. This information, along with the empirical evidence collected from the CAD lectures and general pedagogical research, were very useful in understanding how CAD is currently taught and was used as the basis of the CMSS material.

In general terms, it was important to consider adult learning to ensure that the principles for accelerated learning and adult learning [De Porter 2008, Keller 1987, Knowles 1984a, Knowles 1984b, Mezirow 2000] were adhered to. Keller’s ARCS model of learner motivation [1987] suggested that there were four aspects that needed to be achieved in order to keep the learner motivated in the material, including Attention, Relevance, Confidence and Satisfaction [Ibid:3], which were taken into consideration in the design of the CMSS material. It was important that the materials clearly explained to the learner why they needed to use the material and to make use of a ‘problem-solving’ approach. Through the consideration of Mezirow’s [2000] principles on adult learning, it was found to be important to ask the learner questions about their product, use examples of how to create other key products and to provide the learner with the necessary knowledge with which to create their product. It was also found to be important to provide the learner with immediate feedback [Gagne 1965].

Kolb’s ELT [1984, Kolb et al. 2000] was an extremely useful source of information relating to selecting the CMSS communication method and was found to be well suited
to learning CAD as it relies heavily on experience. The four learning styles noted by Kolb et al. [2000] were used to identify key traits of the learners and communication methods to present the CMSS material were then selected to ensure that a variety of different learning styles were allowed for.

It was also very important to consider visualisation, which was noted as being a key aspect of 3D CAD education in relation to using the CAD system and understanding 3D CAD models. Fischer’s [1991] work was useful in understanding the models that designers of computer-based material have of the system and its users. With regard to visualising 3D CAD models, it was found that likening the models to ‘real-life’ objects aided visualisation [Richards 1995, Mahoney 2000].

Four approaches were used to communicate the CMSS material (computers – website, group work, print and tutorials), in order to appeal to all four of Kolb’s learning styles (‘Accommodating’, ‘Diverging’, ‘Assimilating’ and ‘Converging’) [Kolb et al. 2000]. A process was described in Chapter Six [refer to section 6.4] that incorporated these communication methods.

**11.5 Finalising the CMSS material**

Having defined the basic content for the CMSS material, it was necessary to generate several versions of the material, to ensure that key messages were delivered successfully to the target audience. These were tested within an educational context between 2003 and 2004. The material was first used within the CAD/CAM Achiever and has since been used within Pro/DESKTOP courses. The final version of the material was used in the main trial in July 2004. Several aspects gained positive feedback and were applied within the final version of the CMSS material:

- Inclusion of a general overview to CMS presentation, as well as an introductory presentation
- Use of ‘overarching’ and ‘detailed’ approaches (using probing questions to define a strategy, as well as information regarding how the strategies can be implemented using the CAD system)
Use of the tyre exercise (working in pairs)
Use of an incentive tutorial
Inclusion of a database of common forms
Inclusion of shared geometry exercises

Additionally, it was established that there was no advantage in simply showing novice CAD users how to use the CAD package, as it was found that this resulted in a disadvantage compared to those who applied Pro/DESKTOP in a design context and even against those who had never used Pro/DESKTOP before. This was therefore taken into account within the final version of the CMSS material, which placed a large emphasis on novice CAD users applying the knowledge that they were learning to their own design projects. Again, it was shown that the knowledge applied in a previous CAD package was ‘transferable’, which may also be true for the CMS knowledge.

The final version of the CMSS material was developed to incorporate the use of computers, group work, print and tutorials. Navigation about the online material was possible via the ‘tabs’ at the top of the page, as well as using the orange ‘back’ and ‘next’ links. ‘Normal’ navigation was possible via Internet Explorer. The online material was split into four sections (‘Home’, ‘Previous Material’, ‘Introductory Session’, ‘The Strategy’ and ‘Support Material’) and to ensure that tracking of the usage of the material was possible, the learner was required log in before they could access any information. This also ensured that the Control Group could not access the material.

The previous material page contained all information used in the introductory session of the main research trial, including ‘Assignment One’, which formed the basis of the evaluation and all of the information from the introductory session (including the introductory and CMS presentation slides, the presentation boards and the CAD exercise). ‘The Strategy’ section was the main strategic element of the CMSS material and encouraged the learner to think about the aspects identified in Chapter Five that were necessary in order to use an effective CMS. ‘The Strategy’ section contained a set of questions leading to detailed information about the specific strategy that should be used, as well as how to set the strategy up and some general tips relating to using CAD.
The support material contained several elements, including the interactive section, the help section (including the facility to email an expert user, helpful links and a frequently asked questions section) and the database of common forms. The ‘database of common forms’ section contained information about how an effective CMS had been used to create several key products.

### 11.6 Testing the CMSS material

The final version of the CMSS material [refer to Chapter Eight] was used in the main PhD trial to test the emergent theme [refer to Chapter Two, section 2.6]. Several questions were used to evaluate the material, as discussed in Chapters Nine and Ten.

The main study showed that the CMSS material allowed product designers to capture their design intent effectively, and model their products using an effective CMS. This allowed those participants involved in the redesign exercise to make design changes in half the time of the Control Group.

It was clear that the disadvantages of using CAD noted previously in Table 1 are potentially negated, as below.

- **Perceived disadvantage:** *Users may not have a thorough understanding of the system [Fischer 1991:16], which could potentially lead to the learner creating the model ineffectively [Bhavnani & John 1997].*
  
  Solution through CMSS material: Through the use of all of the basic features, ‘overarching’ and ‘detailed’ approaches, learners were able to create their CAD models using an effective CMS, suggesting that they therefore had a thorough understanding of the relevant features in the system.

- **Perceived disadvantage:** *Users may find it hard to make design changes to their CAD model if they have not modelled the product effectively.*
  
  Solution through CMSS material: Through the use of the CMSS material, learners were able to make changes to their product quickly and effectively.
- **Perceived disadvantage:** *CAD could hinder creativity [Lawson 2002] if the learner is driven by the CAD package rather than their design ideas (e.g. through a lack of experience).*

  Solution through CMSS material: Through the use of all of the basic features as well as understanding CMS, users were able to accurately capture their design intent. However, the extent of the learners’ confidence in relation to their creativity was not explored within this research and could be an interesting area for further investigation.

- **Perceived disadvantage:** *For a novice CAD user, modelling on CAD could take longer than sketching during the initial conceptual stage of the design process.*

  Solution through CMSS material: Time spent using the CMSS material when working on the CAD models during the early stages of the design process would benefit the user during the latter stages, as the designs would potentially be easily modified. This would be especially useful when undergoing client approval, or at the rapid prototyping stage as they would have created their CAD model in a way that would allow them to make modifications easily and generate several variations of their design using CAD.

It was also clear that the participants who used the CMSS material showed the following traits, as noted in Chapter Two, Figure 19:

- Competent CAD users
- Able to employ effective CMS
- Able to create a realistic looking models
- Able to make design changes quickly and easily

The findings from the main study have implications on teaching and learning of CAD generally and it is believed that the CMSS material could be used in CAD education within schools, colleges, universities and industry. This is innovative because the CMSS material can be used alongside existing ‘feature-based’ CAD training material, to provide the strategic element to the learners’ CAD modelling education.
If applied in reality, designers could create realistic looking, accurate models that they could exploit throughout the process of design, for example, when rapid prototyping or creating engineering drawings. In particular, these findings have significant implications for industry, particularly when in a client meeting scenario. Typically, if a client asks for a change to be made, the CAD designer would have to go away and make the changes. However, in this research, it was shown that the participants could make their changes in half the time of the Control Group. In fact, many of the changes were made to the model so quickly, that it would be feasible to make the changes to the model in real time, even at a client meeting. If a designer spent 7 hours a week making changes to their CAD models, this could be reduced significantly, potentially saving over 26 working days a year (based on a 7 hour working day).

Following the results of the main study, it was decided to submit a funding bid for further development of this resource to the ‘Engineering Centre for Excellence in Teaching and Learning’ (Eng CETL). The funding bid was successful and work is currently being undertaken on developing the CMSS material so that it can be used within the undergraduate curriculum at Loughborough University (work in progress screen prints can be seen in Figures 67 and 68).

Figure 67: CADalyst resource - Example 1
It is therefore recommended that CMSS material be introduced to CAD education.

11.7 Limitations

Having gained feedback on the CMSS material and how it was communicated, it was necessary to consider the limitations of the research, as detailed below:

- Empirical evidence has not been collected regarding the effectiveness of the CMSS material in real design house/agency settings, therefore generalisations have been made within the conclusions.
- Assumptions made from the redesign exercise are made based on empirical evidence from a relatively small sample size, potentially restricting their generalistability to the entire population.
- The review of existing CAD material is not an exhaustive account, rather it presents the content of each type as a basis for further work in the thesis.
- Assumptions were made regarding the notion of the CMSS material working across different 3D CAD modellers, such as Solid Works. It is postulated, albeit with reference to Wiebe’s [2000, 2003] empirical evidence of transfer of knowledge between CAD packages, that the CMSS knowledge would transfer between different 3D CAD modellers.
11.8 Contributions to knowledge

The research has contributed to knowledge in the fields of design and engineering the following ways:

- It has been shown that novice CAD users can be taught to use effective CMS.
- A prototype tool has been created that has been shown to support the teaching of novice CAD users to use effective CMS and novice CAD users benefit from this strategic approach when assessed against those who have been subjected to a ‘traditional’ CAD education.
- A combination of three key approaches (‘feature-based’, ‘detailed’ and ‘overarching’) were found to be necessary in terms of the content of the CMSS material.
- Knowledge transfers between Pro/DESKTOP and Pro/ENGINEER when Pro/DESKTOP is used significantly.

11.9 Conclusions

As noted at the outset of this chapter, the overall aim of this research was to develop effective CAD Modelling Strategies (CMS) and investigate the impact of these strategies on novice CAD users.

Developing CMS for product designers was noted as being a key area for development, as it was found that although novice CAD users could create realistic looking models, often, they were not able to make design changes to their model easily. Therefore, through various iterations, the CMSS material was created. This was evaluated on a number of key areas, as identified previously in the research [refer to the definition of CMS in Chapter Two, section 2.2] and it was found that the participants exposed to the CMSS material had generally used a more effective strategy to model a product on CAD than those who did not use the material (the Control Group). For those that were examined in detail, this resulted in them being able to make key design changes to their models in half of the time of the Control Group, which infers implications on the teaching and learning of CAD. It is believed that this research programme has been a
success having addressed the key research objectives and having contributed to knowledge in the ways listed in section 11.8.

11.10 Recommendations for further work
Although the CMSS material provides an interim solution to the gap in knowledge, it is suggested that it can be improved further to provide a bespoke solution for use in CAD education. Therefore, recommendations for further work are as follows.

Incorporate the improvements noted at the end of the Main Study [refer to Chapter Nine, section 9.5.5].
By incorporating the suggestions noted by the participants in the CMS Group in the Main Study, it is believed that the CMSS material could be improved further.

Establish long-term user testing of the CMSS material to consider the impact of the CMSS material on CAD users in industry and those learning to use different CAD packages.
It would be interesting to implement the CMSS material within industry to undertake further testing (especially if the participants were learning to use a different CAD package, having already learnt to use Pro/ENGINEER), to establish whether the learners changed their Behaviour [Kirkpatrick 1998] as a result of the intervention of the CMSS material. In an industry environment, formal training time might be limited and training would happen under different conditions, perhaps with different motivations for undertaking the training. Additionally, it would be interesting to establish how well this material works on those learners who do not necessarily want to learn, and are only undertaking the training to achieve a higher goal, e.g. pass coursework, with no intention of using CAD during their academic or working careers.

Establish whether the participants within the CMS Group used effective CMS in future projects.
As mentioned in Chapter Nine, long-term user testing of the CMSS material would be necessary to establish whether the users changed their behaviour [Kirkpatrick 1998]. This could be achieved by analysing their CAD models later in their academic career.
and within industry, if possible. By analysing the CAD models, it would be possible to see if the learners applied any of the strategies that they learnt through the use of the CMSS material. This could be completed at a number of different periods of time, to monitor their progress as they became more ‘practiced’. Crucially, a redesign exercise would need to be undertaken as this would establish whether the CMSS material allowed the learners to make key design changes quickly and effectively.

**Consider, in more depth, the transfer of knowledge of significant and non-significant use when learning a new CAD package.**

It was found that non-significant use of a CAD package could actually be a hindrance to novice CAD users, and it would be interesting to consider in more depth what impedes these learners. As mentioned previously, Fischer [1991] provides a good example of the mental models that are generated by three groups of stakeholders using a complex computer system, and it might be interesting to establish whether this correlates with the seemingly poorer results of ‘non-significant’ use. The participants could then also be assessed on the functionality of the CAD package to see if they have clear mental models relating to the system. This could be achieved through a questionnaire targeted at novice CAD users to establish which are significant and which are non-significant users. It would then be necessary to interview them in depth throughout their CAD lectures to investigate a) any problems they had, b) what was difficult and c) what was easy.

**Establish what aspects of the CMSS material transfers between CAD packages.**

It is envisaged that the main theoretical principles of the CMSS material are generic across different CAD platforms. However, it would be interesting to establish whether all aspects of the CMSS material do indeed transfer, perhaps by testing it on a platform such as SolidWorks. Theoretically, the testing could follow Wiebe’s model [Wiebe 2003], which would mean that:

a) The participants are trained in the CMSS material  
b) The participants use Pro/ENGINEER for a specific length of time  
c) The participants complete an exercise using Pro/ENGINEER  
d) The participants complete the same exercise using SolidWorks
A similar analysis could then be undertaken to that described in Chapter Nine.

It is believed that the findings detailed in this thesis provide a platform for further work in this area.
12 REFERENCES

**Alias StudioTools, 2003.** *Alias StudioTools: Art to Part*, CD-ROM


**Beckert, B.A. 1997.** “Making the move to 3D design”. In *Computer-Aided Engineering*, 1(1), pp12-14


Fedler, R. M. 1996. “Matters of Style”. In ASEE Prism 6(4), pp18-23


Gagne, R.M. 1965. The conditions of learning. Holt: Rinehart


Australia: Addison Wesley Longman Austraila Pty Limited


**Miles, M.B. and Huberman, A.M. 1984.** *Qualitative data analysis: A sourcebook of new methods*. London: Sage


Paterson, J. 2003. “Using CAD imaging in training and development of engineers”. In The Structural Engineer, February 2003


Toogood, R. 2006a. Pro/ENGINEER WILDFIRE 3.0 Tutorial and multimedia CD. Mission: Schroff Development Corporation


APPENDIX

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Appendix 1

Participant information
## Appendix 1-1: Participant overview

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</table>
Appendix 2

Literature search
Appendix 2-1: Literature search strategy

Several literature searches were conducted to ensure that an accurate representation of prior art was presented. In order to ensure that the literature searches were thorough, systematic and complete, a specific, highly structuralistic research strategy was followed, using robust databases. This ensured that the search targeted specific keywords and, more importantly, could be repeated at a later date.

Primarily, a list of keywords were identified, with particular care being taken to look at the synonyms and related terms, American terms, spellings, word endings and abbreviations (this was especially important with the phrase Computer Aided Design). An example of a mindmap related to ‘learning’ can be seen below:

![Mind map of keywords specific to the subject of ‘learning’](image)

Several different sources were used, including Metalib, OPAC and various newspaper articles and library CD-ROMS. Searches were also carried out using general search engines such as ‘Google’, as well as more specific databases such as ‘Web of Science’. Further searches were carried out in Loughborough University Library with monthly journals, such as ‘Time-Compression Technologies’, ‘CAD User’, and ‘Design News’. The British Library was also used on several occasions to locate items that were difficult to acquire from other sources. Several mailing lists were also subscribed to, including the ‘PhD Design List’, the ‘DRS List’, and the ‘Design Research’ list. These mailing lists provided an on-going source of up-to-date information and links.
Appendix 2-1: Literature search strategy

The two databases were created at the beginning of the research program to log the following searches:

- Subject Resource Directories (9 databases were initially searched)
- Loughborough University OPAC search (to undertake ‘keyword’, ‘author’ and ‘title’ searches)

Metalib was an invaluable source of information, and was used to make sure that a wide range of databases were considered and investigated thoroughly and systematically. Keywords were entered into a Microsoft Excel Database so that a formal log could be established and the results were recorded whilst undertaking the Metalib search.

A screen print of the database can be seen below:

![Database of results of ‘Metalib’ search](image)

Database of results of ‘Metalib’ search

A ‘references’ database was then set up to keep track of all of the useful items that were found from the Metalib ‘Database Search’, as can be seen below.
Appendix 2-1: Literature search strategy

A second Microsoft Excel Database was set up in order to keep track of three literature searches that were undertaken using the Loughborough University OPAC system. The three databases logged the ‘Keyword’ searches, ‘Author’ searches and ‘Title’ searches. The relevant references were then recorded and referenced, as before, onto another worksheet entitled ‘Useful Items’. The ‘Useful Items’ database was very helpful in terms of cross referencing articles that were found twice (e.g. from the ‘Keyword’ search and the ‘Title’ search), as can be seen below.
# Appendix 2-1: Literature search strategy

Database showing results of the Loughborough University OPAC ‘Keyword’ search

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<th>Search Keyword</th>
<th>Sub-Result</th>
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*Cells that are not relevant: no results found*

*Too many results found: search needs to be refined*

Reference sheet - contains all references of useful items found
Appendix 2-1: Literature search strategy

Database showing the referenced items from the ‘Keyword’, ‘Author’ and ‘Title’ searches

Having conducted all of the literature searches, it was then important to take into account the suitability of the articles that were found. This included looking at the date the article was written, whether the article had been updated (e.g. if it originated on the Internet), the article’s audience (i.e. language of article – basic/technical) and whether the focus of the article was popular or academic. It was also necessary to consider the author, to discover their academic credentials, their position within the field and also the thoroughness of their work.

Strengths of this methodology meant that the searches would not be repeated unnecessarily, could be referred to at a later date and could be repeated later in the study to double check that more recent literature had not been published. However, it should be noted that setting up the databases and inputting all of the relevant data was time consuming.

Several literature searches were conducted throughout the course of the research using a highly structuralistic research strategy to ensure that the information that was collated was thorough and complete.
Appendix 3

Sample questionnaires
Appendix 3-1: 'Practiced' CAD users questionnaire for advanced CAD modelling group [Chapter Two]

Please could you fill in the following questionnaire, which will form part of my MPhil research. I am researching into CAD modelling strategies, and this questionnaire refers to your final year CAMM module, and the assignment that you have undertaken. All responses from this questionnaire are confidential and will only be used as part of my research. Thanks very much for your time, Clare Allsop

If you would like any feedback from this questionnaire, you can contact me by email at C.V.P.Allsop@lboro.ac.uk.

Section 1: General Questions

1.1 Have you had a year out in industry?  □ Yes  □ No

1.2 Did you use CAD during your year out in industry?  □ Yes  □ No

1.3 Please indicate which of the following CAD packages you have used before, e.g. at school:
- Pro/ENGINEER
- Pro/DESKTOP
- Rhino
- AutoCAD
- Mechanical Desktop
- VX Vision
- CATIA
- 3DStudioMax
- CDRS
- Solid Edge
- Other (Please Specify)……………………………………………………………………………………………

1.4 In what context have you used these CAD packages?
- In education (School, University)
- In industry
- In my spare time
- Other (Please Specify)……………………………………………………………………………………………

1.5 Has using CAD previously helped you to use Pro/ENGINEER?  □ Yes  □ No

1.6 If yes, briefly explain how:

…………………………………………………………………………………………………………………………
…………………………………………………………………………………………………………………………

1.7 Are you intending to use CAD in your major project?  □ Yes  □ No

Section 2: The CAMM Assignment

2.1 Did you feel that it was an advantage to have thought about the way you were going to model your product before you started using Pro/ENGINEER for the assignment?  □ Yes  □ No

2.2 Did you do any supplementary sketching work, to support your CAD modelling?
- Yes, before I started modelling
- Yes, whilst I was modelling on CAD
- No

2.3 If yes, did you hand it in?
- Yes  □ No, but it is still available to look at  □ No, and it is not available to look at
2.4 Did the tools on Pro/ENGINEER work as well as you had imagined they would?
☐ Yes ☐ No (Please explain)
………………………………………………………………………………………………………………
………………………………………………………………………………………………………………
………………………………………………………………………………………………………………

2.5 Did you find that sometimes a particular feature in the CAD software did not model your part correctly, so chose to use a different feature instead?
☐ Yes ☐ No

2.6 If this was the case, please explain why the first method that you tried did not work:
………………………………………………………………………………………………………………
………………………………………………………………………………………………………………
………………………………………………………………………………………………………………

2.7 Did you use a trial and error approach to modelling your product on Pro/ENGINEER?
☐ Yes ☐ No ☐ Sometimes

2.8 If you were going to model the product again, would you model it in exactly the same way as you did for this assignment?
☐ Yes ☐ No

2.9 If not, please explain what you would do differently and why:
………………………………………………………………………………………………………………
………………………………………………………………………………………………………………
………………………………………………………………………………………………………………

2.10 Did you follow the original modelling strategy that you handed in previously, i.e. did you use the features in the same order that you specified before you started modelling on Pro/ENGINEER?
☐ Yes ☐ No

Section 3: Additional Comments

PLEASE RETURN QUESTIONNAIRES TO BOX LABELLED “CAMM QUESTIONNAIRES” OUTSIDE TONY HODGSON’S OFFICE. THANK YOU
Appendix 3-2: Introductory questionnaire [Chapter Nine]

Introductory Questionnaire

Thank you for taking part in this study. Please could you fill in the following information about yourself.

### Section 1: Your Details

1.1 Name........................................................................................................................................

1.2 Age ......................

1.3 □ Male     □ Female

### Section 2: About your use of CAD

2.1 How long have you used Pro/ENGINEER for?

□ Never             □ Less than one week       □ Less than one month

□ Less than six months □ Roughly one year      □ Over a year

2.2 Which of the following Pro/ENGINEER features can you use?

□ Blend          □ Extrude       □ Hole          □ Shell          □ Round       □ Revolve

□ Surfacing (using style feature) □ Sweep        □ Swept Blend □ Pattern

2.3 Please rate your expertise of using Pro/ENGINEER?

□ Novice         □ Moderate     □ Expert

2.4 Have you ever used any other CAD packages before?

□ 3D StudioMax □ Alias          □ AutoCAD         □ Mechanical Desktop

□ Pro/DESKTOP   □ Rhino          □ SolidWorks      □ TrueSpace

□ VX Vision

□ Other – Please Specify ...........................................................................................................

2.5 What was your A-Level major project?

..............................................................................................................................................................

2.6 Did you use CAD in your major project?

□ Yes          □ No
**Evaluation Questionnaire 1**

Thank you for taking part in this study. Your views and opinions are very valuable to this project. I would appreciate it if you could complete the following questionnaire:

| Name | …………………………………………………………………………………………………………………………… |

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</tr>
<tr>
<td>☐ Very unhelpful</td>
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<td>1.3 Would you recommend this to other students learning Pro/ENGINEER?</td>
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</tr>
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<td>1.4 Do you think it is important to teach this content?</td>
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<td>1.5 Has this made you think differently about the way you will model products on CAD?</td>
</tr>
<tr>
<td>☐ Yes</td>
</tr>
<tr>
<td>1.6 Did you have any problems with any of the material?</td>
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| | | | |
| | | | |
| | | | |
| | | | |

| 1.7 Please list some of the ways the resource could be improved: |
| | | | |
| | | | |
| | | | |
| | | | |
Section 1 Continued: About the CAD modelling strategies material (introductory session & web based resource)

1.8 Please list any suggestions for content that should be added:

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

Section 2: Additional Comments

__________________________________________________________________________

__________________________________________________________________________

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Appendix 4

Sample interview transcripts
Appendix 4-1: Interview transcript – Full [P903A]

[START]

[1] RES Right there we go, I’m just going to put that [the Dictaphone] there.
[3] RES Just a couple of questions really regarding the material, do you feel that you are a confident CAD modeller having used this material?
[4] P903A Erm, I wouldn’t say that I was confident but I think that it helped me.
[5] RES Ok, do you feel that you can capture your design intent effectively using the material?
[6] P903A Yeah yeah it helped me do that a lot.
[7] RES Ok, and do you feel that the material has helped you to use Pro/ENGINEER for designing products?
[8] P903A Yeah it’s good to come back to as well.
[9] RES …as in having had a break?
[11] RES After Easter? Ok, and will you be using the strategies you learnt in future projects?
[12] P903A Yeah definitely I will on the scooter.
[13] RES Oh yes
[15] RES …Did you have any problems with the material?
[16] P903A I don’t I don’t really think so I think like erm I found it a bit hard to grasp at first but once I did it…
[18] P903A Er sort of repetitively er…
[20] P903A It made, it sort of got in to my head and I can sort of…
[22] P903A Especially like all the copy geometry and all that kind of stuff.
[23] RES Yeah.
[25] RES Was it quite daunting …
[26] P903A Yeah it is.
[27] RES When you first use it?
[28] P903A Especially cos erm I hadn’t done it I hadn’t had any em like we hadn’t been taught any sort of computer programs at school whatsoever, and so when we came here it was really difficult and I find it quite, just it didn’t click, but this helps it with that.
[29] RES How do you think the resource could be improved? Just to elaborate on…
[30] P903A Em…
[31] RES Any comments there if you want to look back at that [the questionnaire].
[32] P903A Yeah ok hang on… [PAUSE] yeah just like er maybe just something which has a a quick help menu, just so that you can quickly go to an…
[33] RES Uh ha.
[34] P903A And sort of like step by step basic maybe something like that.
[35] RES Yeah what like a you can search for something?
[36] P903A Yeah.
[37] RES Like Windows help?
Appendix 4-1: Interview transcript – Full [P903A]

[38] P903A Yeah.
[39] RES Sort of thing yeah ok erm was there anything else or?
[40] P903A No that’s it.
[41] RES Do you have any suggestions for actual content which should be added? I know you said like the help, more help...
[42] P903A Yeah no I think that’s I think that’s fine.
[43] RES Ok and did you have any problems when you were modelling it – your project?
[44] P903A Erm...
[45] RES Before Easter?
[46] P903A Modelling this hole punch?
[47] RES Uh ha.
[48] P903A Erm [PAUSE] only, not not with your program, but only like because Pro/ENGINEER seemed so like you can change one thing and then it won’t it dis-aligns everything else.
[49] RES Yeah.
[50] P903A And that’s the only problem I really found – it’s really time – I spent a hell of a lot of time on it.
[51] RES Yeah.
[52] P903A When I think that, I don’t know, from what I’ve heard with some other programs you can sort of mould it the project, er product much shorter and quicker.
[53] RES Yeah.
[54] P903A This is more like engineering based rather than sort of for the designer.
[55] RES Yeah.
[56] P903A If you want to just knock up a quick something that looks good.
[57] RES Did you have any problems when redesigning your project, product?
[58] P903A Yeah erm no just because it wasn’t really.
[59] RES Yeah.
[60] P903A Working when it was regenerating I think. [RENDERED VIEW]
[61] RES Yeah.
[62] P903A But em…
[63] RES Yeah that was a problem, but I mean, it er should have worked.
[64] P903A Yeah.
[65] RES I’ll have to have a look into that.
[66] P903A Ok.
[67] RES Erm, was there anything else?
[68] P903A No that was it.

[END]
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

CON-POS

[11] RES ...do you feel that the material has helped you to use Pro/ENGINEER for designing products?
[12] P901A Yeah it has helped, it has helped with the, as I said the copy geometry and the reference geometry because then the parts all change automatically.
[14] P901A Erm and you don’t have to work out dimensions so easily.
[16] P901A Yeah I think that is the most useful thing I’ve got out of it.

[21] RES ...Did you have any problems with the material itself?
[22] P901A No I don’t think so, I think it was all quite clear because it was all on the website.
[24] P901A And then I think we printed one out.
[26] P901A Yeah because it was easier to look at while you were doing the exercises, erm, no it was fine.

[7] RES do you feel that the material has helped?
[8] P902A Yeah it has um...
[12] P902A Yeah no it has because it made me think of like just getting the basic product done and then constraining it all and making sure it fits.
[14] P902A Together because I thought that would be the hardest.
[16] P902A And it helped me like navigate it around.
[18] P902A So I could save one bit and then um like, for instance, I put in my base and then I tried to put in another part and it was just completely wrong and it didn’t work so I found I could you know take that bit out and put in another piece first and switch it and change it.
[20] P902A And urm that sort of thing, which really helped. It was a lot easier than I actually anticipated it to be.

[27] RES ...do you feel that this material has helped you to use Pro/ENGINEER for designing products?
[28] P902A Yeah I think it has definitely erm it’s just really helped me in lots of places when you think about a product and then when I put it into CAD what I do first and how I do it as well because otherwise it just goes wrong

[34] P902A But I think definitely it has made me think about it a lot easier than the more like step by step way.
[36] P902A Which is good.

[7] RES ...do you feel that the material has helped you to use Pro/ENGINEER for designing products?
[8] P903A Yeah it’s good to come back to as well.
[9] RES ...as in having had a break?
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

[15] RES ...Did you have any problems with the material?
[16] P903A I don’t I don’t really think so I think like erm I found it a bit hard to grasp at first but once I did it…
[18] P903A Er sort of repetitively er…
[20] P903A It made, it sort of got in to my head and I can sort of…
[22] P903A Especially like all the copy geometry and all that kind of stuff.

[5] RES …do you feel that this material has helped you to use Pro/ENGINEER for designing products?
[6] P904A Erm in a way, erm it gives you me more erm greater understanding of how to use the program.

[44] RES …do you feel this material has helped you to use Pro/ENGINEER for designing products?
[45] P905A Yeah it has made me you know erm just explore the program a bit.

[7] RES ...do you feel that the material has helped you to use Pro/ENGINEER?
[8] P906A Yeah I think it has

[29] RES ...Did you have any problems with the material at all?
[30] P907A Not so far no.
[36] P907A But I think that actual thing is really helpful and like definitely more helpful than say what we’ve been given like our lessons and like we’ve been given some COAch something and that wasn’t and I didn’t find that particularly helpful.
[38] P907A But I’m finding yours more helpful.

[11] RES …do you feel that this material has helped you to use Pro/ENGINEER for designing products?
[12] P908A Yeap erm I thought it was very well laid out as well because like with the screen shots and that.
[14] P908A It helped quite a lot so.

[33] RES …How do you think the resource can be improved?
[34] P908A Erm, I don’t really know because like I said I found it quite helpful and well laid out so.

[7] RES ...do you feel that this material has helped you to use Pro/ENGINEER for designing products?
[10] P909A I’d be completely lost without it I think
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

[13] RES do you think that this material has helped you to use Pro/ENGINEER for designing products...?
[14] P9011A Erm it’s given me a different view how to do it which I find easier than other methods that I’ve been taught so yes.
[16] P9011A But I need to be able to remember it.
[18] P9011A I need to look back on my notes.

[29] RES Ok, how do you think that the resource can be improved?
[30] P9011A Erm, you could maybe make, I don’t know – it’s all available online isn’t it?
[31] RES Yeah.
[32] P9011A Other than that there’s not really a great deal more you could do. I mean you put a few screen shots on, other than that doing stage by stage screen shots which is going to be very laborious.
[34] P9011A So probably no. Other than doing that.

CON-NEG
[8] P904A But some of it is not too clear.

[13] RES ...Did you have any problems with any of the material? ...Can we just expand on ... the questionnaire? ...So too much writing, ... too many words on the screen?
[14] P904A Erm in the erm strategy how to do.
[16] P904A Model something.
[18] P904A Um the sheets were too covered in writing to be honest...
[20] P904A So it wasn’t really easy to follow.
[21] RES Sure – was that the paper based stuff?
[22] P904A Paper based stuff yeah.

[1] RES ...do you feel that you are a confident CAD modeller having used it?
[1] P905A Not really, I feel like… before I’d come here to do this course that.
[3] P905A I’d done no Pro/ENGINEER as such…
[5] P905A So I think that the strategies were a bit beyond me to be honest, I mean I’d like to give it another go now.
[7] P905A Because I feel more confident that I can use Pro/ENGINEER but I think at the time it was a bit … too much.

[48] RES ...Did you have so just to elaborate on the problems you had with the material?
[49] P905A I think it’s just erm a general understanding I mean with like what they are and what is happening, again I think it just goes back to my inexperience of using Pro/ENGINEER.
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

[50] RES Some of the ways that the resource can be improved? Or how to apply the strategy to actual product?
[51] P905A Yeah because again you know when you pumped in the answers to your software, I mean just having, working out how to apply feedback from that…
[53] P905A Onto your model.

[54] RES Oh right so like another stage between getting the strategy out…
[55] P905A Yeah because you just like use copy geometry for this part.
[57] P905A And then it's just having to yeah just applying that strategy to…
[59] P905A How to go about making your model.

[8] P906A Yeah I think it has but I think the problem was…
[10] P906A Erm because I haven’t done that much Pro/E anyway, I found it difficult to sort of sort of copy geometry and everything.
[12] P906A Erm but now because I’ve used all the features and everything I think if I look at your notes now, and sort of try and apply it.
[14] P906A It will sort of help in the future it’s like with the scooter I haven’t really used it.
[16] P906A Because I don’t really understand it at the moment.
[18] P906A Erm but I think in future, and once I get used to Pro/E I will be able to use it.

[32] P906A Sort of just going through the list, and I could actually do it, it’s just the others I didn’t really like grasp.

[44] P906A …That erm assembly guide thing remember that?
[45] RES Um, yeah.
[46] P906A Erm which, I had a look at but couldn’t really get my head round.
[51] RES How do you think that the resource, the CAD modelling strategies as a whole could be improved?
[52] P906A Erm, [PAUSE] I think what you gave us was good, it’s just that the time was a bit too soon to…
[54] P906A For us to actually get our heads round it straightaway.

[57] RES And does that come back to again not having learnt all the features?
[58] P906A Um yeah cos I can’t remember now, how many weeks into term was it?
[59] RES Erm, [PAUSE], it was, I think, quite early on, possibly about week 7 or 8, it was not right at the beginning but yeah...
[60] P906A I just felt that I hadn’t really got to grips with Pro/E at the time.

[31] RES Oh cool ok and how could the resource be improved do you think?
[32] P907A Well I have forgotten the website to go on.
[34] P907A It was quite a long time ago.
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

[17] RES Did you have any problems with the material?
[18] P908A Erm… not really it’s just like I said before, erm I couldn’t get copy geometry to work on a 3D sketch.
[44] P908A Yeah well I I remember that erm like we copied geometry…
[46] P908A At first I did find it a bit difficult because er we hadn’t really like used any of those settings before.

[15] RES Ok cool and did you have any problems with the material?
[16] P909A Erm not really I suppose erm I did get the sheets muddled up so…
[18] P909A The sheets I didn’t find the sheets were clear…
[20] P909A Clearly like what order they were in.
[24] P909A But sort of reading through them you could follow them just about yeah so…

[25] RES …do you think that it would be better not to have like step by step stuff and erm…
[26] P909A Er step by step it was good.
[28] P909A Erm, but I suppose sort of more defined parts I think probably.
[30] P909A It was it was sort of each one led into the other and then you sort of erm um if you missed a couple out and...
[32] P909A Then you had to follow back through it.
[34] P909A And it did get a bit confusing I thought but I mean…
[40] P909A I mean it says you’ve got to use this and this…
[42] P909A Um and right mouse click there but erm and I’m just trying to do that and there were quite a few different ways that…
[44] P909A I can’t really explain it but it’s um…
[45] RES Like different ways you can do the same thing and there are different options that you can click that aren’t necessarily on the sheet that…
[46] P909A Yeah I mean the sheet it did go through quite…
[48] P909A Urm quite thoroughly what you were doing but I don’t know whether it’s just I’m not very good with computers.
[50] P909A I found you sort of got lost a bit…
[52] P909A From where you were actually going.

[16] P9011A But I need to be able to remember it.
[18] P9011A I need to look back on my notes.
[24] P9011A I had some problems with reference-reference geometry because it um just confused me the way you had to sort reference everything together against each other and I kept getting tied up in how to do it, and it just wouldn’t do it so!
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

CON-ADD
[34] P901A Erm like maybe going through I know we did those sheets on how to do it but erm my problem was not recognising the right features of…
[36] P901A Like I couldn’t recognise whether it was a revolve or an extrude or something, so maybe going through some more of those parts.
[40] P901A I found how to use them but like I can’t see how erm whether it is better to use an extrude or whether it is better to use a sweep or it it’s better to use a revolve.
[42] P901A I can’t recognise that and that’s where I lost marks.

[43] RES ... So you think maybe you could do some more detailed information on why you’d want to use like a…
[44] P901A Yeah.

[45] RES Revolve and why?
[46] P901A And where it would be most appropriate.
[48] P901A Because that’s what they never explain to us and then they marked us down for it

[37] RES ...Did you have any problems with the material itself? Like anything that you feel could be improved or...
[38] P902A No just maybe if it was like um more of like a step by step guide.
[40] P902A With a possible picture of where each thing was, because even trying to like navigate yourself around Pro/E.

[45] RES ...Have you got, so suggestions for content – do you think that there should be more about where you find all these different aspects?
[46] P902A Yeah possibly about where you find it and then like erm step by step you know you click on this and then you do that and erm just so it a really I know it’s sort of like a one, two, three but so that it sets it out for every one.
[48] P902A In a way.

[29] RES How do you think the resource could be improved? Just to elaborate on...
[32] P903A Yeah ok hang on… [PAUSE] yeah just like er maybe just something which has a a quick help menu, just so that you can quickly go to an…
[34] P903A And sort of like step by step basic maybe something like that.
[35] RES Yeah what like a you can search for something?
[36] P903A Yeah.
[37] RES Like Windows help?
[38] P903A Yeah.

[25] RES... The step by step stuff?
[26] P904A Yeah yeah it’s be easier erm if er you know, if you had an animated animated way something showing you how it’s done, on the screen.
[28] P904A Talk through.
[29] RES Like a video type thing?
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

[31] RES Ok.
[32] P904A That would appeal to me.

[33] RES ...Could you elaborate on how the resource could be improved, you said it could be animated like you say and talked through.
[34] P904A Just show how all the features work, so every part of Pro/E explained.
[36] P904A Like you’d have a large model tree thing showing you everything.
[37] RES Yeah, ok like all the features and things?
[38] P904A Yeah and…
[39] RES Like you were saying sweeps and things?
[40] P904A Yeah erm, so erm if you wanted to know how to do a curved surface…
[41] P904A You could go in to erm, into the features…
[43] P904A And erm pick, you could have a pro start off saying erm how to what features to use.
[45] P904A So you’d type in curved surface and then it would tell you to er erm, er use the sweep blend…
[47] P904A Or whatever type and then you could have a tutorial type of thing so you can go into the features and it will tell you how to use that or like a feature.
[48] RES So you mean like even like a database where you can say what you want to create and it would tell you, like but on a sort of a detailed level, so if you wanted a curved surface there are, these are the ways you could do it and there are probably lots of ways.
[49] P904A Yeah.
[51] P904A And then having a programme to tell you how to use that feature.

[99] RES So that’s something you think could be incorporated maybe into the material some more clear instructions?
[100] P906a Yeah.

[101] RES About the assembly?
[102] P906a Yeah erm, because I suppose, I don’t know I’m maybe just speaking for myself, but when I was assembling it I was just assembling it just so it looked…
[104] P906A Right on screen, but if you came to change anything or just if you, because later if you needed to move things don’t you.

[52] P907A I don’t know how you can really… I don’t if there is any way that you can explain that because I think that it just fails you for almost no reason.
[62] P907A I don’t know if that could be explained somehow…
[64] P907A I don’t even know if there is a way again whether it’s just…
[66] P907A A case of clicking though.

[35] RES ...Were there any other problems you had with the material do you think – anything else you can you think of, or ways that it could be improved or…
[36] P909A Erm [PAUSE] well I suppose not well I suppose maybe erm exactly I mean it does say like mouse click here there and everywhere but…
Appendix 4-2: Interview transcript – Coded and clustered [Chapter Nine – positive and negative comments relating to the content of the CMSS material]

[38] P909A Maybe more a bit more specifically how you go about using different parts.

[53] RES ... *do you have any suggestions for content that could be added?*
[56] P909A Erm maybe a couple more screen shots.
[58] P909A Of erm the menu bars maybe um…

[35] RES ...**do you have any suggestions for content that could be added? Could you elaborate on this?**
[36] P9011A Yeah but it would be nice from a novices’ point of view, to I mean you tried to like give us an overview of what it can do, it’d be nice to see how you can model it and it all explode out and like go and do that.
[37] RES The flashy stuff?
[38] P9011A Yeah it’d just be cool to sort of know how to do that so that you can…
[40] Sort of take it all the way through to presentation.
[42] P9011A It’d be a nice thing to do.
[44] P9011A Rather than, it’s just that I know a few people who have tried to do the design practice work on Pro/E.
[46] P9011A And erm it’s not actually, you don’t get asked to do a presentation but if you were asked, it’d be really nice to be able to do that and know how to do it.
Appendix 5

CAD models [Chapter Nine]
### Appendix 5-1: Models produced by the CMS Group and the Control Group [Chapter Nine]

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Rendering 
Development 
Working 
Drawings |   |
### Appendix 5-1: Models produced by the CMS Group and the Control Group

**[Chapter Nine]**

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### Appendix 5-1: Models produced by the CMS Group and the Control Group

[Chapter Nine]

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<td><strong>P911B Additional use:</strong></td>
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Appendix 5-2: Sample CAD model analysis [Chapter Nine – P903B]

Assembly:
The base part ‘2C.PRT’ and the ‘LEVER.PRT’ have been constrained using the ‘fix’ constraint. The other parts have been assembled ‘normally’, although ‘allow assumptions’ has been selected in some parts. The ‘fix’ constraint has been used to constrain the SPRING.PRT. A sub-assembly has been used to assemble the LEVER.PRT and the PINS.PRT (four times).

- A sketch was created of the profile of the part.
- This sketch was extruded.
Appendix 5-2: Sample CAD model analysis [Chapter Nine – P903B]

- A smaller sketch was then created of the profile of the part.
- This was extruded as a cut into the part.
- Circular sketches were created.
- These were extruded as a cut through the whole part.
- A rectangular shaped sketch was created, which was extruded as cut through the whole part.
- A rectangular sketch was created, which was extruded as a cut into the part.
- A chamfer was added.
- A round was added.

**BASE_COVER.PRT**

- A sketch was created of the profile of the part.
- This was extruded.
- A smaller sketch was then created of the profile of the part.
- This was extruded as a cut into the part.
- A chamfer was added.
- Rounds were added.

**RIVET.PRT**

- A sketch was created containing a half profile of the part.
- This was then revolved about a central axis.
A rectangular shaped sketch was created, which was extruded.

A triangular shaped sketch was created on the side of the part, which was extruded as a cut through the whole part.

Rounds were then added.

A sketch was created containing three circular sections.

This was then extruded as a cut through the whole part.

An ‘e’ shaped sketch was created, which was extruded as a cut through the whole part.

A curved sketch was created, which was extruded the width of the part.

A round was then added.

A rectangular shaped sketch was created, which was extruded as a cut through the whole part.
Appendix 5-2: Sample CAD model analysis [Chapter Nine – P903B]

PUNCH.PRT

- A circular sketch was created, which was extruded.
- A triangular sketch was created, and extruded as a cut through the whole part to form the detail at the top of the part.
- A chamfer was added.
- A circular sketch was created, and extruded as a cut through the whole part.

LEVER.PRT

- A sketch was created of the top profile of the part.
- This was extruded and the part was shelled.
Appendix 5-2: Sample CAD model analysis [Chapter Nine – P903B]

- A sketch was created containing the detail on the side of the part, which was extruded as a cut through the whole part.
- A curved sketch was created on one end of the part, which was extruded.
- A curved sketch was created on the other end of the part, which was extruded.
- A sketch was created containing two circular profiles.
- A round was added.
- The sketch containing the two circular profiles was then extruded as a cut through the whole part.

PIN.PRT

- An axis was created running through the top and right datum planes.
- A sketch was created containing half the profile of the part, which was revolved.
- A chamfer was added.
- Rounds were added.
- A circular profile was created, which was extruded into the part as a cut.
- A chamfer was added on the cut.
- A round was added.
A helical sweep was created.
A circular sketch was created on the top end of the helical sweep.
This was extruded.
A circular sketch was then created at the bottom end of the helical sweep, using the ‘create an entity from an edge’ tool to select the circular geometry.
This was extruded.
A cross shaped sketch was created at the bottom top of the part using two lines.
Datum points were added.
A datum plane was set up on one of the crossed lines using the datum points.
Another datum point was created.
Another datum plane was created on the other crossed line using the datum points.
Appendix 6

CAD exercises and examples used in the CMSS material [Chapter Nine]
Appendix 6-1: Shared geometry exercises

Exercise: Profile-Profile
Download 'gps_top.prt'
Download 'gps_back.prt'

Aim: Create screen from a cut, so that if the cut is changed, the screen also changes.

1. Open ‘gps_top.prt’.

2. Create a new sketch on the top face of the GPS part using the sketch icon.

3. Sketch the shape of a screen for your GPS, making sure there are no ‘extra’ lines - you could use a ‘normal’ shaped screen or a curved screen:

4. Complete the sketch by clicking on the ‘tick’ button.

5. Extrude this sketch as a cut by highlighting the sketch so that it appears in red, and clicking on the extrude button as usual.

6. Make sure that the sketch that you have just created is not hidden (it will appear grey if it is, and if so, right click on it and select ‘unhide’). Save the part. You should be left with a cut similar to this:
Appendix 6-1: Shared geometry exercises

7. Create a new file and call it ‘screen.prt’. Save this file and exit from it.

8. Create a new assembly file, and assemble the ‘gps_top.prt’ into the assembly and constrain it using the default constraints.

9. Assemble the ‘screen.prt’ into the assembly, and assemble it using the default constraints.

10. The next step is to copy the geometry for the ‘screen.prt’ from the ‘gps_top.prt’. You need to ‘tell’ Pro/E which of these two parts you want the new geometry to go into, and in this instance, it is the ‘screen.prt’. Right click on the ‘screen.prt’ and click ‘activate’. This means that any geometry that is copied will be copied into the ‘active’ part.

11. Next, click on the ‘insert’ menu at the top, then ‘shared data’ then ‘copy geometry’. This will bring up a dialogue box at the top of the screen and you will be asked to specify what geometry you want to copy. Click on ‘curve refs’ and ‘define’, leave the ‘one by one’ option highlighted (which will allow you to select individual curves to be copied into the new feature) and select the curves in the sketch that you created in order to extrude the screen cut. You may need the ‘hidden line view’ on to see the sketch. You will need to hold down ‘Ctrl’ to select more than one curve. Select ‘done’. Also, click on ‘misc refs’ and make sure ‘datum plane’ is selected, and select ‘TOP_SURFACE_DATUM’ which will give you a datum plane to sketch on in your new part.

12. When this has been completed click ‘done’ and ‘ok’. Save the assembly.
Appendix 6-1: Shared geometry exercises

13. The geometry has now been copied.

14. Right click on the ‘screen.prt’ on the ‘model tree’ and select ‘open’. You can see that this curve has now been copied. You can now use this to create an extrusion. Click on the new sketch icon using the copied datum plane to sketch on (and the right datum plane as a reference) and use the ‘create entities from edge icon’ to select the curve that you have just copied. Click the tick button to exit from the sketch, and create an extrusion 1.5mm below the datum plane from this sketch in the same way that you did before.

15. Save this part and open up the assembly.

16. You will see that the ‘screen.prt’ has appeared in the correct orientation. Save the assembly and close all windows.

17. Open up the ‘gps_top.prt’ and alter the initial sketch (note: the SKETCH not the extrusion), and alter the shape of the screen. You could use a design similar to that below:

![Screen Design](image)

18. Save this part and open up the ‘screen.prt’. The screen shape will not change until you click on ‘edit’ and ‘regenerate’. Notice that the screen shape has now updated.

19. If you open up the assembly you will see that it has updated here too.
Appendix 6-1: Shared geometry exercises

Exercise: Reference-Reference

Download 'gps_top.prt'
Download 'gps_back.prt'

Aim: Create locations for holes.

1. Open up ‘gps_top.prt’.

2. Create new ‘datum points on a surface’ using the following icon:

3. Sketch on the following surface:

4. Create the following sketch to place the datum points, using centre lines, as can be seen below (note you might need to ‘pull out’ the line menu to find the centre line option):

5. Finish the sketch by using the .
Appendix 6-1: Shared geometry exercises

6. Create an extrusion on the inside face of the top casing, as can be seen:

7. Use the datum points that you have just created as references for this sketch by clicking on them when you are defining your references.

8. Create four circles on each of the datum points - make sure one of them has a diameter 4mm. Use the constraints toolbox \(=\) to select the equal constraint \(=\). Select the circle with radius 4mm, and then select one of the other three circles. You will notice that the circles are now equal sizes (r1). Do the same with the other two circles. Finish the extrusion using the \(\checkmark\) icon, and extrude the circles 7mm as can be seen below:

9. Save the file and close it.

10. Create a new assembly file and assemble the ‘gps_top.prt’ and the ‘gps_back.prt’ components in place as can be seen below:

11. The next step is to copy the datum points from the ‘gps_top.prt’ into the ‘gps_back.prt’. You need to ‘tell’ Pro/E which of these two parts you want the new geometry to go into, and in this instance, it is the ‘gps_back.prt’. Right click on the ‘gps_back.prt’ and click ‘activate’. This means that any geometry that is copied will be copied into the ‘active’ part.
Appendix 6-1: Shared geometry exercises

12. Next, click on the ‘insert’ menu at the top, then ‘shared data’ then ‘copy geometry’. This will bring up a dialogue box at the top of the screen and you will be asked to specify what geometry you want to copy. Click on ‘misc refs’ and make sure ‘dtm point’ is selected, and select the four datum points that you created earlier. You may need the ‘hidden line view’ icon to see the points. You will need to hold down ‘ctrl’ to select all four points. When you have done this, click ‘ok’ and then click ‘ok’ again to finish the operation.

13. Right click on the ‘gps_back.prt’ and click ‘open’. You will now see that the four datum points have been shared into this part as well.

14. Create another extrusion on the inside face of the ‘gps_back.prt’, using these four datum points as references, and extruding in the same way as you did before - four circles, diameter 4mm, using the ‘equal constraint’ and extruding 7mm.

15. Your model should now look like this:

16. Save the ‘gps_back.prt’ and close it.

17. Open up the assembly file again, and notice that the extrusions that you created are very close to the button holes. All you will need to do is to move the datum points that you created initially to resolve this.

18. Open up the ‘gps_front.prt’ again, and right click on the datum point feature that was created originally, and click ‘edit definition’.

19. Alter the distances of the datum points, as can be seen below:
Appendix 6-1: Shared geometry exercises

20. Finish the sketch by clicking on the ✔️.

21. As you can see, your extrusions have now moved. Save this part.

22. Now open up the ‘gps_back.prt’ and click ‘edit - regenerate’ (otherwise the changes will not be seen).

23. As you can see, the extrusions in this part have also moved as a result of changing the original datum points sketch.
Appendix 6-1: Shared geometry exercises

Exercise: Pattern
Download 'gps_top.prt'
Aim: Create another row of buttons using the pattern feature.

1. Open up the ‘gps_top.prt’.

2. Right click on the extrusion ‘DETAIL_EXTRUDE’, and click ‘edit definition’. Click on ‘placement’ and ‘edit’. Click on ‘sketch’. As you can see - a ‘normal’ sketch has been created for this part. However, instead of creating three more of these sketches below this one to add more detail to the part, it will be easier to simply pattern this feature. Click the tick and exit from this feature.

3. Right click on this ‘DETAIL_EXTRUDE’ feature in the ‘model tree’ and select ‘pattern’.

4. Click on the top dimension tab, and for the first dimension, click inside the box below ‘direction1’ and select the vertical ‘20’ dimension.

5. In the increment box, click ‘5’. This is the distance (including the feature) between each instance of the extruded cut. You want 6 instances of this feature, so type in ‘6’ in the number of instances box, as can be seen below:

6. Click on the box to finish this operation.

7. As you can see, you now have 5 other versions of this extrusion.
Appendix 6-1: Shared geometry exercises

Exercise: Duplicate-Part

Download 'gps_top.prt'

Aim: Create a mirror image of the top of the GPS part to use as the bottom casing as an independent part.

1. Create a new assembly part.

2. Assemble ‘gps_top.prt’ into the assembly using the default constraints.

3. Click on ‘insert - component - create’ (or use the shortcut icon).

4. Ensure that the options are the same as those below, and click ‘ok’.

5. Select the ‘copy’ option, to ensure that the part is independent (if you wanted a dependant part then you would click ‘reference’). Select the ‘gps_top.prt’ as the part reference, and the bottom surface of the part as the planar reference, as can be seen below:

6. Click ‘ok’ and open the new part that you just created (by right clicking on the new part in the ‘model tree’ and selecting ‘open’). Delete all the features that you do not need in this part, as can be seen below, making sure that you do not delete the mirror operation.
Appendix 6-1: Shared geometry exercises

7. Right click on the ‘MAIN_EXTRUDE’ feature and alter the height of the extrusion to 5mm.

8. Save this part.

9. Open the assembly that you created earlier, and click ‘edit - regenerate’.

10. Notice that you now have a mirrored copy of the original part, in which you can edit specific features.
Appendix 6-2: Tyre exercise - Groups A, B and C

Please have a look at the rendering and line drawing below, of a tyre. Please model this part in Pro/DESKTOP using the instructions below.

GROUP A Wheel example – why is it important to consider modelling?

1. Extrude a circle (R20, d40) by 20mm, as can be seen below:

2. Cut into the circle (R15, d30) all the way through the part, as can be seen below:

3. Cut through the part with another circle (R18, d36) through 18mm as can be seen below:
Appendix 6-2: Tyre exercise - Groups A, B and C

4. Create one of the tread extrusions, as can be seen below:

The finished model should look like this:

GROUP B Wheel example – why is it important to consider modelling?

1. Sketch a circle (R21, d42), as can be seen below, and set up the construction lines so that you can sketch the tyre treads as part of this extrusion:
Appendix 6-2: Tyre exercise - Groups A, B and C

2. When the construction lines are in place, sketch the treads for the tyre onto this sketch. (You will need to use constraints for this, such as the parallel, tangent and perpendicular constraints). When the sketch is complete, extrude the profile by 20mm.

3. Cut through the part with a circle, radius (R15, d30) through 18mm, as can be seen below:

The finished model should look like this:
Appendix 6-2: Tyre exercise - Groups A, B and C

GROUP C Wheel example – why is it important to consider modelling?

1. Revolve the following section by 360 degrees:

2. Create one of the tread extrusions, as can be seen on the following page, and extrude it through 20mm:

3. Pattern this extrusion (20 patterns at 18 degrees).

The finished model should look like this:
Appendix 6-3: Case study – Implementation of ‘The Strategy’ output on a typical CAD model

Perfume Bottle

To start, ‘The Strategy’ section online was used to get a good idea of how to model the parts.

1. Do you have any idea of what your product will look like?
   Yes, pictured above.

2. Are any of your parts symmetrical and/or do any of your parts need to share geometry, or fit together exactly?
   Yes, therefore we need to use the detailed strategy.

Detailed strategy output:

Product: Perfume Bottle

Time Taken: 15 seconds

The Strategy:
Use the 'detailed strategy' - see output below:

The Strategy Output:

<table>
<thead>
<tr>
<th>Parts to create</th>
<th>Strategies to use for each part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Revolve, Profile-Profile (with Lid)</td>
</tr>
<tr>
<td>Lid</td>
<td>Revolve</td>
</tr>
</tbody>
</table>
Appendix 6-3: Case study – Implementation of ‘The Strategy’ output on a typical CAD model

Step by step guide:

Base (base.prt)

1. Create the following sketch to create a revolve, as can be seen below:

Note: Remember that if you are going to need to change the shape of the spline, you will need to fix the two axis that you are dimensioning everything from to ensure that when you change the shape of the spline, it will not change anything else.

2. Revolve this profile by 360 degrees, and add a round to the bottom edge:

3. Save this part as the ‘base part’.
Appendix 6-3: Case study – Implementation of ‘The Strategy’ output on a typical CAD model

4. Create a new datum plane on the top surface of the lip for the perfume bottle, and create a new sketch on this datum plane, picking the edge highlighted below using the ‘create entities from edge icon’.

5. Create a new assembly file, and assemble this part into the assembly using the default constraints.

**Lid (lid.prt)**

5. Create a new ‘blank’ part called ‘lid.prt’ and save it.

6. Assemble this part into the assembly using the default constraints.

7. Right click on the ‘lid.prt’ and click ‘activate’.

8. Share the sketch that you created in the previous part (circular sketch), by clicking on insert - shared data - copy geometry, and selecting this sketch under ‘curve refs’. Click ok and save the assembly.

9. Open up the ‘lid.prt’ again and create a new sketch on the perpendicular datum plane to this sketch. Use the copied sketch as a reference, and copy this line into the new sketch.
Appendix 6-3: Case study – Implementation of ‘The Strategy’ output on a typical CAD model

10. Create the profile for this

11. Revolve the sketch.
Appendix 7

Sample presentation
Appendix 7-1: CMS presentation [Chapter Nine]

CAD Modelling Strategies

Clare Allsop: Research Student
Design and Technology
Loughborough University

What are CAD modelling strategies?

- A CAD modelling strategy is the strategy that you use to generate a model on CAD.

- A good CAD modelling strategy means that you have used the most effective feature, set of features, or technique on CAD to generate your form.

- Using a good CAD modelling strategy could save you time, and make it easier to make design changes at a later stage of your project.
Types of CAD modelling strategies

- **Trial and error modelling strategy**
- **Separate modelling strategy**
- **Sharing modelling strategy**
  - Symmetry/Revolve/Sweep
  - Profile-Profile
  - Reference-Reference
  - Pattern
  - Duplicate Part

### Symmetry/Revolve/Sweep

The symmetry strategy can be used either:

- a) to mirror geometry within Sketcher
- b) to mirror a feature/set of features.

**Advantages:**

- When first part sketch/feature changes, so does second.
- Saves time.
Appendix 7-1: CMS presentation [Chapter Nine]

**Profile-Profile**

Use a profile (or sketch) from one part...

... and share it, so that it can be used in another part.

Advantages:
- If you modify the original sketch, it will update in all the parts that it is used in.
- Saves time

---

**Reference-Reference**

Use references from one part (e.g. datum plane, datum point etc.)...

... and share them, so that they can be used in another part.

Advantages:
- If you change the location of the reference on the original part, the locations in the new part will change too.
- Saves time
Appendix 7-1: CMS presentation [Chapter Nine]

Pattern
This is where you would use the pattern feature to:

a) Create numerous copies of one feature.

b) Assemble numerous copies of the same part.

Advantages:
• If first feature/part changes, so does second
• Saves time

Duplicate Part

This is where you can...

a) create an exact copy of a part (dependently or independently)

b) create a mirror image of a part.

Advantages:
• If you change the original part, the new part will change too.
• Saves time
Appendix 7-1: CMS presentation [Chapter Nine]

Summary

- Symmetry/Revolve/Sweep
- Profile
- Reference
- Pattern
- Duplicate Part
Appendix 7-1: CMS presentation [Chapter Nine]

Why are CAD modelling strategies important?

CAD modelling strategies are important to think about because this could mean that:

- It is easier to make design changes to your CAD model.
- You could save time modelling it
- Your parts may be more robust
- You will not need to spend time ‘practicing’ what features to use

Introduction to material

1) Log onto the learn server.

2) Type in the following address:

   https://learn.lboro.ac.uk/ssh/cd/cms/

This resource contains three sections

a) Previous material – this is the material from this introductory session
b) The Strategy – the main tool on this resource
c) Support section – if you get stuck or need extra help
Appendix 7-1: CMS presentation [Chapter Nine]

Section 1: Previous Material

This section contains links to:

• First presentation
• Presentation boards that are displayed in this room
• Exercises that you will go through
• This presentation

Section 2: The Strategy

This section contains a web based tool that determines effective strategies to use to generate your products using CAD (specifically Pro/ENGINEER).

You use this section by following instructions that are given.

If you have any problems, please email
C.V.P.Allsop@hboro.ac.uk
Section 3: Support Material

This section contains links to:

• A database containing a number of common forms and how they have been created using 'The Strategy'.

• An interactive section: https://learn.lboro.ac.uk/phorum/misc/list.php?f=28
  — follow this link to this website now and try posting a question/replying to someone's question.

• A help section containing frequently asked questions, links to helpful websites, and an email address to email if you have any problems.

Help

C.V.P.Allsop@lboro.ac.uk
Appendix 8

Computing for Designers Assignment
Appendix 8-1: Assignment One [Chapter Nine]

CfD1: Assignment 1: 2005: CAD Model of Familiar Product

Background:
You have now covered many of the basic functions of within Pro-E and should be in a position to start modelling on your own. You are being asked to model a familiar product which should be chosen carefully to allow you to show your grasp of the modelling functionality covered to date. You may have to adapt the design to enable you to include all feature types. If in doubt about the suitability of the product you have chosen then consult a CfD1 tutor.

Assignment:
Your assignment is to create a Pro-E model of either: a hand-held hole punch, a stapler, a mobile phone or a pocket calculator. The model should be based on a real object from which you can take measurements. The product should be created as several separate part files brought together into a fully, appropriately constrained assembly file.
The completed rolling assignment model also forms part of this assignment.

The assignment will be marked in three ways:
1. The range of Pro-E features used to produce the model. The complexity of the features used and the modeling approach used (how logically and economically the model was created). The quality of the assembly. [65%]
2. The design of the model produced in terms of how accurately it reflects a manufactured product. [25%]
3. The satisfactory completion of rolling assignment ‘perfume bottle’ model [10%]

Assignment Marking criteria:
Pass – 40%: Use of all the feature creation types and other modeling functionality used to date. An assembly of at least three parts. Completion of rolling assignment ‘perfume bottle’ model
First – 70%: A model who’s form gives the impression of a manufactured product. Multiple use of the more complex feature creation types and modeling functions with a complex underlying structure. A fully constrained assembly with well considered and applied constraints. Completion of rolling assignment ‘perfume bottle’ model

Marks will be subtracted for inappropriate use of feature creation methods, ie. blends, extrusions and rounds used to create a part which could be a single revolved feature.
Marks will also be lost for application of inappropriate assembly constraints.
Good file management is an intrinsic part of the modeling process – particularly when constructing assemblies – **check your files before submission.** Give your files sensible names and do not submit version files or other unrelated files.

Submission Requirements: A folder with your user ID (ie. cdspk) as its name containing an assembly file and all associated part and sub-assembly files to be submitted electronically to a group-filestore [details of which will be published before the deadline] before 5pm on the 28th January 2005.
Appendix 9

Final CMSS Material
Appendix 9-1: Final CMSS Material

The final version of the CMSS material, which was used in the main PhD trial is detailed within this section of the Appendix. The main aim of the material was to educate CAD users who, through the use of the material, would become competent users who could easily make design changes to their CAD models. This version of the material was generated through the numerous Pro/DESKTOP trials [refer to Chapter Seven].

The final version of the CMSS material was presented as a blended learning offering, which combined interactive, web-based material with printed aspects, tutorials and group work.

Print-based material and presentations
The design of the print-based materials (shared geometry exercises and introductory booklet) and presentation (introductory presentation and CMS presentation) followed the web based graphic styling closely and aimed to provide clear and concise instructions for the learner. The following approach was used to design and produce the print-based material and presentation:

1. The copy for the material was generated in Microsoft Word. This enabled the author to read through the copy and ensure that the language used was appropriate, that it was clear and that it was concise.
2. A ‘mock-up’ artwork was created
3. The final copy was inserted into the ‘mock-up’ artwork
4. The material was printed

Interactive web-based element
Having discussed the interactive requirements and general design of the web-based element of the CMSS material with two IT experts (one at Loughborough University to ensure that the material was compatible with the university servers and one professional web developer), it was decided that a mixture of Microsoft FrontPage and PHP should be used to create the material. It was not within the scope of the research for the researcher to learn to program with PHP, so a PHP programmer was used to generate the coding used behind the database aspect of the material. The design phase of the interactive material was undertaken using three different stages.
Appendix 9-1: Final CMSS Material

1. The copy for the material was generated in Microsoft Word.
2. A storyboard version of the content was created, which was necessary to provide implicit instructions to the PHP programmer of the interaction required within the material.
3. A ‘mock-up’ of the artwork was created so that the PHP programmer could create a template in which to input the copy that the researcher generated. The design and layout of the screen was extremely important and was considered in great depth. A study on colour was undertaken, which was used to make decisions about the colour combinations used. A screen print of the chosen colour themes and general design of the material can be seen below.

Navigation about the online material was possible via the ‘tabs’ at the top of the page, as well as using the orange ‘back’ and ‘next’ buttons. ‘Normal’ navigation was possible via Internet Explorer. The online material provided different levels of information for the learner to access and was split into four sections, as below.
Appendix 9-1: Final CMSS Material

- ‘Home’ – this allowed the learner to view an overview of what was contained within each section of the material
- ‘Previous Material’ – this allowed the learner to view all of the material that had been presented to them in the ‘Introductory Session’
- ‘The Strategy’ section – this was the main section of the material and allowed the learner to generate a printable CMS for any product that they needed to design
- ‘Support Material’ – this contained an interactive section, help section and a database of common forms if the learner required assistance

Before the learner could access any of the information, they were required to ‘log in’. The log-on page was useful to generate statistical information about the users of the online material, for example, how often they visited the site.

Print-based material
The print-based materials used within the main PhD trial included:

- Printed CAD exercises (shared geometry exercises, tyre exercise)
- Printed introductory booklet
- Introductory PowerPoint presentation
- CMS PowerPoint presentation
- Printed presentation boards

The printed CAD exercises acted as an incentive to undertake the learning, as did the presentation boards. The aim of this element was to ensure that the learner understood what could be achieved if they continued to use the material. In Pilot Study One [refer to Chapter Four], it was found to be necessary to ensure that learners were shown the potential to exploit the CAD model and to learn how to make use of shared geometry. Also, by providing the learners with a step-by-step exercise, it was possible to provide them with clear examples of how those features that were perceived as more ‘complicated’ could be used [refer to Chapter Four]. The tyre exercise was used to illustrate to the learner the time implications of using an ineffective method to model on CAD with and the benefits of using an effective method.

Printed CAD exercises (shared geometry exercises)
Four CAD exercises were used (profile-profile, reference-reference, pattern and duplicate part), which aimed to guide the learner through the notion of shared geometry [refer to Appendix 6]. A key outcome from Pilot Study One and previous literature [Richards 1995, Mahoney 2000] was that parallels should be drawn between the product being modelled and the tangible ‘real-life’ object, so both CAD exercises involved ‘real-life’ examples.
Appendix 9-1: Final CMSS Material

The learning aim of the shared geometry exercises, involving a satellite navigation system, was to reinforce the CMS issues discussed in the previous introductory section and to provide a basis for understanding how the strategies can be implemented within a CAD model. This exercise, along with the presentation boards [refer to Chapter Two] were positioned as an ‘incentive’ tutorial for the learners, so that they could understand what was possible on the system [Toogood & Zecher 2006]. The satellite navigation system was felt to be suitable because it highlighted how four fundamental strategies (both ‘overarching’ and ‘detailed’ approaches) can be implemented within one product:

- ‘Profile-profile’ strategy exercise [refer to Chapter Five]
- ‘Reference-reference’ strategy exercise [refer to Chapter Five and below]
- ‘Pattern’ strategy exercise [refer to Chapter Five]
- ‘Duplicate part’ strategy exercise [refer to Chapter Five]

Exercise: Reference-Reference

Download 'aps_top.prt'
Download 'aps_back.prt'

Aim: Create locations for holes.

1. Open up 'aps_top.prt'.
2. Create new datum points on a surface using the following icon:

3. Sketch on the following surface:
Appendix 9-1: Final CMSS Material

Having completed all four exercises, the learner had:

- Created a ‘screen’ part for the product, which updated automatically when the original sketch used for cutting the hole was modified
- Created four extrusions referenced to four datum points, which automatically updated when the original datum points were redefined
- Created a row of buttons using the pattern feature, which automatically updated when the pattern was redefined
- Created a mirror image of the top part to use as the bottom casing (as an independent part)

This showed the learner that a number of key strategies could be used within the same product, which could save them time at a later stage in the design process. Another important aspect was allowing the learners to download part files for use within the exercises, which helped them to visualise the parts to be created and ultimately saved them time. The exercises were necessary as it was found to be important to exploit aspects of 3D CAD that would otherwise be difficult to explain without the use of technology [Scanlon et al, 1987, Dwyer 1980 – refer to Chapter Six].

The tyre exercise was also used and followed the same format as per Chapter Seven [refer to Appendix 6].

A ‘skeleton’ strategy exercise was also created, involving a computer mouse, in order to reinforce the CMS issues discussed in the previous introductory section. This strategy had been termed the ‘skeleton’ strategy within Pro/ENGINEER. The mouse was felt to be suitable because it highlighted how a ‘skeleton’ model worked very clearly and was typical of the ‘type’ of models that product designers might be creating, as can be seen below.
Appendix 9-1: Final CMSS Material

As part of the exercise, the learner was informed that there were three main strategies that could be used to model the four parts of the mouse (two buttons, top and bottom part), including:

- Creating all four parts separately
- Creating the main shell of the mouse and then saving this model under different file names and cutting away from each model to form the part
- Creating a ‘skeleton’ model

The learner was then asked to modify the split line of the mouse using a step-by-step exercise, involving the ‘skeleton’ model. This showed the learner that using an effective strategy to model their part could make a difference to the time it takes to make design changes and reinforced the need to consider the CMS carefully. It should be noted that the ‘skeleton’ strategy is very important when learning to use surface modelling, but in the context of 3D parametric solid modelling, is a more advanced function and was therefore not used in its entirety as a teaching approach within the research.

Printed introductory booklet
The introductory booklet detailed the format and timings for the session and the website address that the learner needed to visit. It also detailed the prerequisites for using the material, which included the learner:

- Knowing what product they were going to model for their University assignment
- Knowing how many parts there were in their chosen product
- Having logged onto the CMS section of the University ‘Learn Server’ successfully

It also asked the learner to record their user number for the web-based material, which was important from an administration point of view.

Introductory PowerPoint presentation
This section contained a PowerPoint presentation and provided the learner with a basic introduction to CMS. Both the PowerPoint presentations were developed as a result of the previous Pro/DESKTOP trials [refer to Chapter Seven]. The slides can be seen below. The aim of this presentation was to give the learners a clear understanding of what they would be expected to do, as well as timescales for the research. Detailed information was also provided regarding the introductory session, as shown below.
Main PhD Trial: Developing CAD modelling strategies for product designers

Clare Allsop: Research Student
Design and Technology
Loughborough University

About the trial

The trial forms the final part of my PhD research, and will be used to evaluate the material that has been developed over the last two years.

Trial split into 3 sections:
1) Introductory session (today)
2) Use of online resources (over next 7 weeks)
3) Evaluation session (beginning of February)

Support sessions will be held on Mondays at 1.30pm.

You will be asked to:
1) Fill in introductory questionnaire and consent form
2) Complete a strategies form
3) Use the web based material to determine your strategy, and use the material to model your Pro/ENGINEER Assignment
4) Fill in two evaluation questionnaires
5) Take part in group discussions

- The results that you provide will be used within my PhD research

- You can withdraw from the experiment at any time, and are under no obligation to give reasons for your withdrawal
Appendix 9-1: Final CMSS Material

**Introduction to session**

This session will involve you:

1) Filling out a questionnaire, a consent form and a strategy form
2) Undertaking an exercise
3) Having an introduction to CAD modelling strategies, and the web based material
4) Determining your strategy using the web based resource

You will then be asked to consider the information that you have received today and to look on the online resource to help you model your Assignment 1 on Pro/ENGINEER. You will then be required to take part in an evaluation of the material.

**CMS PowerPoint presentation**

An additional PowerPoint presentation was then provided, giving the learner more detailed information about ‘overarching’ approaches. This presentation can be found in Appendix 7.

**Printed presentation boards**

Printed presentation boards were used to provide a further visual introduction to the subject, and were originated from the research carried out in the ‘Exploratory Study’ [Chapter Two]. The presentation boards can be seen in Chapter Two. The presentation boards provided case study examples of effective and non-effective CMS.

**Interactive web-based material**

The following section details the interactive web-based aspect of the CMSS material and includes a description of:

- The home page
- The previous material section
- ‘The Strategy’ section
- The support material

**Home page**

The Home Page of the online material provided the learner with a list of the different sections contained within the online material.
Appendix 9-1: Final CMSS Material

Previous material

The previous material page contained all of the information used in the introductory session of the main research trial [refer to Chapter Nine and screen print below]. It was necessary to include the material used within the introductory session within the online material to ensure that the learner could revisit the information at a later date, to allow them to learn in their own time.

The previous material page contained links to the following:

- **Copy of the CAD assignment**
  ‘Assignment One’ contained full details of a CAD assignment set as part of the undergraduate coursework on Industrial Design and Technology at Loughborough University. This can be seen in Appendix 8.

- **Introductory presentation**
  A link to download the introductory presentation was included in this section so that the learner could revisit any of the points from the introductory session.

- **Presentation boards**
  A link to download the printed presentation boards was included in this section so that the learner could revisit any of the points from the introductory session.

- **Shared geometry exercises**
  Copies of the shared geometry exercises were available in this section, so that the learner could work straight from the computer or to print the exercises as necessary, depending on their learning style [Kolb 1984, Kolb et al. 2000].
Appendix 9-1: Final CMSS Material

- **CMS presentation**
  A link to download the CMS presentation was included in this section so that the learner could revisit any of the points from the introductory session.

‘The Strategy’

‘The Strategy’ section, shown below, was the main strategic element of the CMSS material. It encouraged the learner to think about the key aspects, identified in Chapter Five, that are necessary in order to select an effective CMS. It provided the learners with a formal planning process, to help them to consider the modifications that would have to be made to the model.

![The Strategy section](image)

‘The Strategy’ section contained a set of key questions leading to detailed information about the specific strategy that should be used, as well as how to set up the strategy. The learning aims for this section were to encourage the learner to think about their model, leading them to a specific strategy. The questions were developed through the Pro/DESKTOP trials and included:

- **Do you have an idea of what your product will look like?** This is asked in order to assess whether the learner had a ‘design in mind’. If the learner did not have a clear idea of what the product was going to look like, they would not have been able to answer any of the proceeding questions. If the learner answered ‘no’ to this question, the most effective strategy for the learners would have been the ‘trial and error’ strategy.

- **Are any of your parts symmetrical and/or do any of your parts need to share geometry, or fit together exactly?** Although it was envisaged that the most common answer to this question would be ‘yes’, it was necessary to ask this question in eventuality that a designer intended to create a relatively simple, one-part product, such as a vase, in which case, the most effective route would be to use the ‘separate’ strategy.
Appendix 9-1: Final CMSS Material

The learner was then presented with one of three combinations of strategies, providing ‘Level 1: Overview information’ [refer to Chapter Six]:

- ‘Trial and error’ strategy [refer to Chapter Five]
- ‘Sharing’ strategy [refer to Chapter Five]
- ‘Separate’ strategy [refer to Chapter Five]

The rationale for the ‘Trial and error’ section of the material originated from Chapter Two. The learner was presented with the question ‘Do you have an idea of what your product will look like?’ and if the learner answered ‘no’, they were directed to the ‘trial and error’ strategy page, as can be seen below. This page guided the learner to create a ‘rough model’ of their design, so that they could experiment with different forms and provided the learner with ‘Level 2: More detailed information’ [refer to Chapter Six]. It was noted that an element of the ‘detailed’ approach could be used within this strategy to ensure that the parts would fit together correctly.

With regard to the ‘Sharing’ strategy, if the learner answered ‘yes’ to the question ‘Do you have an idea of what your product will look like?’ then they were directed to the next question, which was ‘Are any of your parts symmetrical and/or do any of your parts need to share geometry, or fit together exactly?’. If the learner answered ‘yes’ to this question, then they were directed to the ‘sharing’ strategy page, which was the main strategic element of the material. This provided the learner with ‘Level 2: More detailed information’ [refer to Chapter Six]. As noted previously in Chapter Five, the ‘sharing’ strategy involves elements of both the ‘overarching’ approach and the ‘detailed’ approach [refer to Chapter Five]. In order to use this section, the learner was required to stipulate how many parts there were in their model and whether any of the parts needed to share geometry.
Appendix 9-1: Final CMSS Material

Primarily, the learner was presented with detailed information regarding the ‘sharing’ strategy and overview information was provided to enforce previous learning points, as can be seen in below.

The text shown in blue in above was hyperlinked to more detailed information, or ‘Level 3: In-depth information’ [refer to Chapter Six]. For example, when the learner clicked on ‘symmetry’ strategy, they were presented with a definition of how the ‘symmetry’ strategy could be implemented, as well as a step-by-step guide on implementing the strategy within Pro/ENGINEER [as can be seen in below]. Additionally, a link was available to the original exercises using the ‘profile-profile’, ‘reference-reference’, ‘pattern’ and ‘duplicate part’ strategies.
Appendix 9-1: Final CMSS Material

Symmetry Strategy

How do I go about creating my part using the symmetry strategy?

The symmetry strategy can be used either a) to mirror geometry within sketcher, or b) to mirror a feature.

Mirroring geometry within sketcher:

1. Create the lines that you want to mirror.
2. Create a centre line with which to mirror them about using the following icon:

3. Highlight all the lines that you want to mirror, by holding down control to select each one.
4. Click on 'Edit' then 'Mirror', and then select the centre line that you have just created, to complete the operation.

Mirroring a feature:

1. Create the feature that you want to mirror.
2. Click on 'Edit' then 'Feature Operations', and within the menu manager, select 'Copy' then, highlight 'Mirror'. Select 'to enable you to select the feature that you want to mirror), and 'Dependant' (which will mean that when you change the initial feature, the mirrored one will change too - if you do not want this to happen, click 'Independent'). Select 'Done'.
3. You will then need to select the feature that you want to mirror (it might be easiest to do this via the model tree on the left hand side). Select 'Done'.

When the learner was ready, they could then move onto the strategic element of the material, as can be seen below.

The learner was first asked to name their product (e.g. ‘Calculator’) and to define how many parts they would be creating. They were also asked to take note of their ‘user number’ (in the top right hand side of the page) and write it down in their printed introductory booklet. This enabled the researcher to log into the administration page of the material [shown below] and view or print any information that had been lost (for example, due to a lost internet connection).
There was also a ‘messages’ area, which highlighted to the learner if there was an error on the page (e.g. if they inputted ‘two’ instead of the digit ‘2’, as required by the system). When the learner had inputted this information, they could then move onto the next page.

The learner was asked to name all of the parts involved in their CAD model, using descriptive names for use in the comparison section (e.g. ‘Button’).
Appendix 9-1: Final CMSS Material

The comparison then asked the learner to whether the part in question was symmetrical, or could be revolved or swept [shown above]. It then compared the part in question with every other part, to establish the relationships between the parts (for example, whether the top of the calculator needed to share geometry with the bottom of the calculator). Instead of simply inputting a ‘yes’ or ‘no’ response, the learner was asked to consider if the ‘profile-profile’, ‘reference-reference’, ‘pattern’ or ‘duplicate part’ strategy could be used, as can be seen below.
Appendix 9-1: Final CMSS Material

When the learner had completed the comparison process, they were then presented with a CMS output, detailing their suggested CMS, as can be seen below. An example of a case study detailing how the strategy could be applied to a CAD model can be found in Appendix 6.
Appendix 9-1: Final CMSS Material

As can be seen, the CMS detailed the name of the product, the time taken to complete the previous questions and the suggested approach for modelling the product. A ‘print this page’ functionality was added to ensure that the learner had a hard copy of the strategy to refer to while modelling. The output listed the suggested strategies for each part in a tabular form (as can be seen above), which was a key outcome from Chapter Four, where it was suggested that learners should be provided with a formal planning process to construct their CAD model.

Additionally, the learner was provided with a step-by-step guide to modelling the part using the strategy listed in the table, providing ‘Level 3: In-depth information’ [refer to Chapter Six], as can be seen below.

How to create your CAD model:

1. Create the first part in the table above. Include all the geometry that needs to be shared with the other parts (under the heading ‘strategies for each part’). Save this part and close it.

2. Create a new assembly file, and assemble the first part into this. Save the assembly file.

3. To create the second part in your table, create a new (empty) part file, and save this as an empty file.

4. Open the assembly file, and assemble the new part file into it using the default constraints.

5. If any geometry needs to be shared into this part from the previous one, right click on the new part file, and click ‘activate’ ‘shared data’ ‘copy geometry’ and select all of the geometry that needs to be shared into this file. If there isn’t any geometry that needs to be shared, continue to step 6.

6. Save the assembly and close it.

7. Open up this new part file you created and continue working on it using the shared geometry to build the part from/build it from scratch. Again, create any new shared geometry features by looking at the heading ‘strategies for each part’ in the table above (make sure you create the shared geometry features OUTSIDE of the feature that you want to use them in).

8. Once you have finished this file, save it, and close it. Open the assembly file again, and check that the new part is correctly assembled. If not, right click on the new part, and click ‘edit definition’, and delete the default constraint. Continue to assemble this part as normal using the ‘normal’ constraints, such as ‘mate’, ‘align’ etc.

9. When you need to create another part file, continue from stage 3.

With regard to the ‘Separate’ strategy, if the learner answered ‘yes’ to the question ‘Do you have an idea of what your product will look like?’ then they were directed to the next question, which was ‘Are any of your parts symmetrical and/or do any of your parts need to share geometry, or fit together exactly?’. If the learner answered ‘no’ to this question, then they were directed to the ‘separate’ strategy page, as can be seen below. As noted previously, in Chapter Five, the ‘separate’ strategy involves elements of the ‘detailed’ approach [refer to Chapter Five]. It was envisaged that the learner would use this strategy if they did not require any parts in their CAD model to link parametrically with other models and would provide them with ‘Level 2: More detailed information’ [refer to Chapter Six].
Appendix 9-1: Final CMSS Material

Another aspect of the CMSS material was the inclusion of ten general tips relating to modelling on CAD, generated from past experience by the researcher. These can be seen below.

1. Save regularly!
2. Make sure that you name the part sensibly - once you share the geometry, you will not be able to change the part name.
3. Do not delete or rename any of the parts that are sharing geometry!
4. Always sketch on a datum plane when you create a new sketch.
5. In sketcher, draw your lines longer than they need to be and then trim the unwanted parts away using the icon. This may reduce the occurrence of ‘stray’ lines where lines do not meet properly and leave a gap.
6. Use constraints when sketching - for example, equal (=), parallel, perpendicular
7. When creating an initial extrusion, extrude both sides of the datum plane instead of just one side.
8. Shared geometry must be from the same part file. If you want to share the geometry from two part files, you simply need to copy the geometry in two parts.
9. Work in the assembly mode as much as possible. When you want to make modifications to a specific part in the assembly mode, right click on the part in the model tree and click ‘Activate’. To ensure that you can see all the features within the part in the model tree, click on ‘Assembly’ just above the model tree, ‘Tree filters’ and put a check box in ‘Feature’.
10. If an error message occurs when you are redesigning your part, click on ‘Quick Fix’ and ‘Redefine’. You may have simply deleted a surface that a feature was relying on. Do not delete the feature!
Appendix 9-1: Final CMSS Material

Support material
The support section allowed the learner to access three main sections, as can be seen below.

- Interactive section
- Help section
- Database of common forms

During the main PhD trial (as discussed in Chapter Nine), the participants were provided with one-to-one support, which was a key outcome from Chapter Four.

Interactive section
The interactive section contained a link to a discussion list, to allow the learners to interact with CAD users of varying abilities and to post messages if they were having difficulties, as can be seen below. This was particularly important to ensure that the learner did not feel isolated and is based on Sabry & Baldwin’s [2003:445] model of ‘Three categories of web-based learning interaction’ and Fischer’s [Fischer 1991:17] ‘Enhance learning by supporting learning on demand’. It also conformed to the principles of social constructivism, which states that learners build up their knowledge from other learners though interaction with them [Pear & Crone-Todd 2001].
Appendix 9-1: Final CMSS Material

Help section
The ‘help’ section included the option to email an expert user, contained helpful links and also contained a frequently asked questions section [shown below]. The helpful links were put together from past experience by the researcher and the frequently asked questions were accumulated as a result of previous trials involving novice CAD users [refer to Chapter Seven].

Helpful Links:
The following links might be helpful:

- PreENGINEER CADTrain CoCo - Click on ‘start’ - ‘programs’ - ‘CADTrain CoCo’ (only on campus)
- http://www.ptc.com/community/prexfernewtools/
- http://www.cadpro.co.uk/brasshelp/
Appendix 9-1: Final CMSS Material

Frequently Asked Questions

What are CAD modelling strategies?
A CAD modelling strategy is the strategy that you use to generate your model on CAD. A good CAD modelling strategy means that you have used the most effective features, set of features, or technique on CAD. Using a good CAD modelling strategy could save you time and make it easier to make design iterations at a later stage of your project.

How can I make sure that I use a good CAD modelling strategy?
To make sure you use a good CAD modelling strategy, it is important to follow the steps in ‘The Strategy’ section.

I’m stuck, and my product is not featured on the database - what can I do now?
There are two main options available to you now, assuming that you have followed all necessary steps in ‘The Strategy’ section. Firstly, you can post a question on the discussion list (https://learn.broco.ac.uk/broconumis/disc.php?f=28), and secondly, you can email an expert user.

I’m stuck - what can I do?
Re-read the introduction, and make sure that you have followed ‘The Strategy’ instructions fully. Also, have a look at the database section, to see if you can see a similar product and get some ideas about a CAD modelling strategy from that. If you have not resolved your problem at this stage, you can post a question on the discussion list (https://learn.broco.ac.uk/broconumis/disc.php?f=28) for other users to answer, and failing that, you can email an expert user.

I can’t find what I am looking for - what shall I do?
You can use the search option to find what you are looking for, or email an expert user to find what you are looking for. Another option is to email the discussion list to see if they can help you. Your address: (https://learn.broco.ac.uk/broconumis/disc.php?f=28).

Database of common forms

The ‘database of common forms’ section contained several different products, which were considered to be examples of typical designs for product designers. This section had been used within the CAD/CAM Achiever Pro/DESKTOP trial [refer to Chapter Seven and Appendix 6] and can be seen below.
Appendix 9-1: Final CMSS Material

Each product contained detailed information about:

- How the CMS had been selected (using ‘The Strategy’ section of the material)
- The CMS output
- How the CMS had been used to build the model, using a step-by-step guide, to allow the learner to replicate the model themselves

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**Sony Digital Camera**

To start, ‘The Strategy’ section online was used to get a good idea of how to model the parts.

1. Do you have any idea of what your product will look like?
   - Yes, pictured above.

2. Are any of your parts symmetrical and/or do any of your parts need to share geometry, or fit together exactly?
   - Yes:

---

**Product:** Sony Digital Camera

**Time Taken:** 3 minutes, 26 seconds

**The Strategy**

Use the ‘detailed strategy’ - see output below:

**Detailed Strategy Output:**

<table>
<thead>
<tr>
<th>Parts to create</th>
<th>Strategies to use for each part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front casing</td>
<td>Profile-Profile (with back casing), Profile-Profile (with Lens), Profile-Profile (with Flash), Reference-Reference (with Battery compartment), Reference-Reference (with Top button), Profile-Profile (with Zoom)</td>
</tr>
<tr>
<td>Back casing</td>
<td>Profile-Profile (with Viewer), Reference-Reference (with battery compartment), Reference-Reference (with Top button)</td>
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<td>Lens</td>
<td>Revolve, Profile-Profile (with Zoom)</td>
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<tr>
<td>Viewer</td>
<td>Symmetry</td>
</tr>
<tr>
<td>Flash</td>
<td>Symmetry</td>
</tr>
</tbody>
</table>
Appendix 9-1: Final CMSS Material

Step by step guide:

Main step by step guide to creating this part involves:

Front Casing (front_casing.prt)

1. Create the ‘front_casing.prt’ by using the strategies listed below:
   - Profile-Profile (with back casing) - create the profile of the camera, and extrude it. This will allow you to share the shape of the camera between the ‘front_casing.prt’ and the ‘back_casing.prt’.
   - Profile-Profile (with lens) - create the profile of the lens on this model, so that it can be shared with the ‘lens.prt’ when it is created.
   - Profile-profil (with flash) - create the profile of the flash on this model (using the symmetry strategy), so that it can be shared with the ‘flash.prt’ when it is created. Extrude this as a cut.
   - Reference-Profile (with battery compartment) - create a datum plane on this model, so that you know how deep to create the battery compartment. Extrude a cut up to this plane.
   - Reference-Profile (with top button) - create a datum plane where the centre of the button is going to be, so that you can share this datum plane with the button part, and use it to sketch the shape of the revolve on.
   - Profile-Profile (with zoom) - create the profile of the zoom on this model so that it can be shared with the ‘zoom.prt’ when it is created. Extrude this as a cut.

2. Save this part.

3. Create a new assembly file, and assemble the ‘front_casing.prt’ part into this. Save the assembly file.

Back Casing (back_casing.prt)

4. Create the ‘back_casing.prt’ by creating a new (empty) part file, and save this as an empty file.

5. Open the assembly file, and assemble the ‘back_casing.prt’ part file into it. Right click on the ‘back_casing.prt’ file, and click ‘activate’. Click on ‘insert’ - ‘shared data’ - ‘copy geometry’ and select the profile of the ‘front_casing.prt’. Use this profile to create the rest of the part.

The aim for this section was to act as a resource for product designers, who would be able to find a product that was similar to the product that they wanted to model and examine both the ‘overarching’ and ‘detailed’ approaches used to create the model. It is envisaged that over time, designers would add to the resource using their own examples.

Summary

The final prototype of the CMSS material was presented as a blended learning offering, which combined interactive, web-based material with printed aspects, tutorials and group work.
Appendix 10

Data [Chapter Nine]
### Appendix 10-1: Results – CAD Analysis [Chapter Nine]

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<th>Verified by expert user</th>
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