University of Strathclyde

Department of Design, Manufacture and Engineering Management

Towards Principles and Project Memories for distributed-Design Information Storing in Engineering Design Education.

By

Hilary J. Grierson

A thesis presented in fulfilment of the requirements for the degree of

Doctor of Philosophy

September 2010

Declaration of Authenticity and Author's Rights

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Hilary Grierson

Date: 28/09/10

Acknowledgements

My sincere thanks go to Professor Bill Ion, my supervisor, for his knowledge, advice, guidance and motivation throughout this long journey; to Dr. Christine Sinclair for her invaluable chats and encouragement and reading of the work; and to colleagues at DMEM for their support whenever needed.

Thanks go to all participants in the studies and focus groups, both in UK and around the world for their time and contributions.

And thanks to David, Megan and Euan for putting up without me, especially during the last nine yards. I love you all dearly.

24/7	24 hours, 7 days a week; all the time
CAPLE	Centre for Academic Practice and Learning Enhancement
CM	Corporate Memory
DMEM	Design Manufacture and Engineering Management
DMS	Data Management System
DRM	Design Research Methodology
EDM	Electronic Data Management
f2f	Face to face
GIM	Global Innovation Management (Postgraduate course at Strathclyde University)
ICT	Information and Communication Technology
IT	Information Technology
KIM	Knowledge Information Management
LTM	Long Term Memory
OM	Organisational Memory
PBL	Problem-based Learning
PDE	Product Design Engineering
PDM	Product Data Management
PjBL	Project-based Learning
PLM	Product Lifecycle Management
PM	Project Memory
SME	Small to Medium Enterprise
STM	Short Term Memory
VC	Video Conferencing
VT	Virtual team

Asynchronous:	Taking place at different times.
Calculations:	Information on early/initial calculations in connection with the performance of product/concepts, (e.g. costs, forces, etc.).
Collocated teams:	Teams comprised of individuals who work together in the same physical location.
Communications information:	Information relating to arrangements to communicate, e.g. planning times for video conferences, meetings, etc.
Contextual information:	Background information; information on aspects relating to the context around the task/work to be carried out, e.g. times available to work, including holidays, etc.
Corporate Memory:	A Corporate Memory is the information a company retains to support its working organisation. It is also referred to as an Organisational Memory.
Data:	Facts or statistics from which information can de derived.
Design rationale:	An explanation of the reasoning, tacit assumptions, design parameters, operating conditions, dependencies or constraints applied in the creation of an artefact or some part of it. (Grubber, 1993)
Distributed design:	Carrying out design at a distance.
Distributed teams: (Global)	Teams comprised of individuals who work and live in different countries and are culturally diverse. They are often also referred to as Global Teams.
Far side:	Distanced side of a global team.
File galleries:	Designated areas in a system where files are stored.
'Follow-the-sun':	A mode of global working in which tasks are carried out daily across distributed sites in different time zones in order to reduce project duration and increase responsiveness.
Formal information:	Formal information and knowledge (often referred to as 'hard') is the primary work product of the worker and is easily and routinely captured. It is factual and informative. Identified as more *product-related*, it is more factual and declarative and is about the outputs and results.
Functional information:	Information on how a product, part, component, etc. performs (e.g. mechanisms).

Informal information:	Informal information and knowledge (often referred to as 'soft') is created in the process of producing the formal results. It is more practice-oriented and gives context to the formal information. Information identified as more *practice-related*, produced as a result of generating the outputs and results.
Information carriers:	The representation of the information e.g. text, sketch, audio, video, etc. Also referred to as media or mode of exchange.
Information content:	The information contained in different information carriers, e.g. information on user requirements, function, materials, testing, rationale, context, procedures, etc.
Information:	Something that can be explicitly told or recorded containing data. Information can be both formal and informal.
Instance of information:	An occurrence of stored information. In text, it can occur as a phrase or sentence or as a word. Instances of information can also be identified in an image, sketch or video.
Knowledge:	An understanding of the information and data in a given context, dependent on experience and beliefs.
Local side:	Each distributed group of a global team.
Locational information:	Information which indicates where design information is stored.
Online (project) sites:	Online environments where information is stored and shared.
Organisational information on tasks:	Project management relating to the team, e.g. log of events; stages of work, processes and progress.
Organisational information on team:	Project management relating to the task, e.g. allocation of roles; assigning of leadership, etc.
Organisational Memory:	An Organisational Memory is a collection of the information an organisation stores that can be used to refer to, to make current decisions. It is also referred to as a Corporate Memory.
Principle:	A principle is a basic truth, law or assumption; a generalisation that can be accepted as true. A principle informs and guides practice.
Prior experience/knowledge:	Anything previously known or experienced from any source that can be brought to a new design problem.
Problem-based Learning (PBL):	Problem-based Learning is a strategy where students are presented with a problem and are required to gather information and new knowledge in order to solve it. It does not require an end product.

Procedural information:	Information on 'how to do things'; procedures for engagement of work.
Project Memory:	A project memory is a store of information and knowledge gathered and generated during a project. A project memory for student use can be described as a shared workspace which captures project practices and results; a collection of stored lessons and experiences from a project. It should be a dynamic and active store not a static one.
Project-based Learning (PjBL):	Project-based Learning is an instructional strategy used to engage students in 'real world', often multi-disciplinary and technology driven tasks, to bring about deep learning. It results in an end product.
Shared workspace:	An online virtual workspace for collaborative working.
Social information:	Personal information about individuals in a team; or, motivational information; or informal 'chit-chat'.
Synchronous:	Taking place at the same time.
Virtual teams:	These teams are comprised of individuals who have a moderate level of physical proximity. For example, located in the same building but on different floors or located in different parts of the same country.
Wiki:	A website that allows the creation and editing of interlinked web pages. Suitable for supporting collaborative work.

Table of Contents

List of Figures

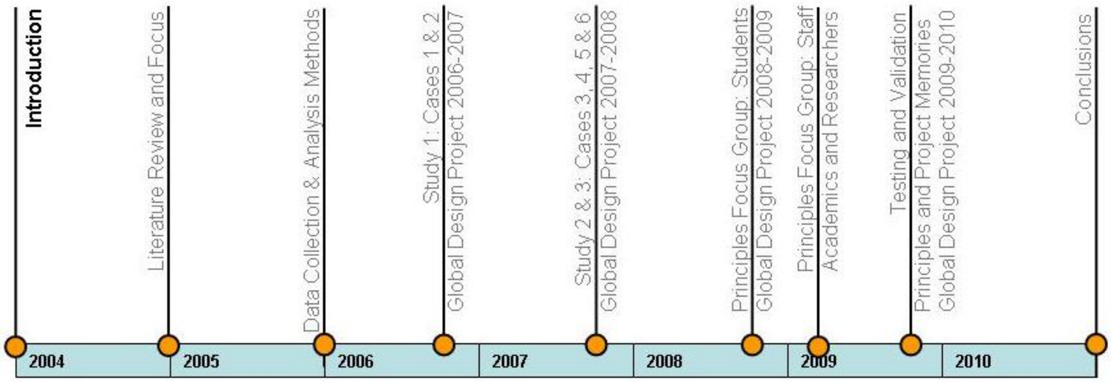
List of Tables

The issues of distributed working are many, with problems relating to information access and information acquisition the most common (Crabtree et al., 1997). Little prescription or guidance on information management exists for designers (Culley et al., 1999). This thesis examines how engineering design students store information in distributed team-based project work. From these findings a set of guiding *Principles for distributed-design information storing* (d-DIS) are developed to support students undertaking distributed project work and to better prepare them for their role as graduate engineers in an ever increasingly international and globalised market. The thesis also presents the development of the concept of *Project Memories,* shared information spaces. It is crucial to provide an archive or repository that functions as a collective memory in order to support distributed design collaboration (Gross et al., 1997).

The work developed in four stages. The first stage reviews the literature in distributed design, engineering design information and the educational context. Stage 2 presents the descriptive element of the thesis, outlining the research methods used and the results and findings of how students store distributed design information from six global design project case studies. The emerging issues from these studies then inform a set of guiding *Principles* and a *Framework* for distributed design information storing, which are presented in Stage 3. The final stage concludes the work with the implementation and validation of the *Principles* and *Project Memory* concept by both academics and students.

Whilst the thesis focus is on the investigation and development of support for distributed design in an educational context rather than an industrial one, with the move in industry to a more information and knowledge intensive environment, the *Principles* and *Project Memories* will be of great value to industry also.

1 Introduction



1.1 Introduction

This thesis investigates **how engineering design students store information in distributed design team-based project work**. The emerging issues and subsequent recommendations support the development of a set of guiding **Principles for distributed-design information storing** (**d-DIS**) to enhance the students' distributed design information storing practices. The thesis also presents the development of the **Project Memory** concept (a shared information space or spaces supporting distributed design work). It is crucial to provide an archive or repository that functions as a collective memory in order to support distributed design collaboration (Gross et al., 1997). With the increasing globalisation of new product development and a move towards a knowledge-based economy, globally distributed collaborations and distributed teams are becoming commonplace in industrialised organisations (Hinds & Mortensen, 2005). Students need to be prepared in order to work in this international and global context. However, the issues of distributed working are many, with problems relating to information access and information acquisition the most common (Crabtree et al., 1997). With developments in ICT, students in Higher Education will be expected to possess more advanced skills in sourcing, managing and sharing vast quantities of digital information (Holden, 2003). This Chapter sets out the context for the thesis, commencing with the **Vision** and motivation for the work in Section 1.2 based on the review of the literature and on the author's experience of working in the area of distributed design over the last ten years. Section 1.3 details the **Research Aims** and **Objectives** and defines the **Research Questions** and **Hypotheses**. The overarching **Research Methodology** selected to direct and add rigour to the work is outlined in Section 1.4, along with an introduction to the research methods used. Section 1.5 presents the **Research Framework** and **Contributions to new Knowledge**. The Chapter then concludes with a **Thesis Map** identifying the chapters in relation to the various stages of the Research Methodology, including a timeline indicating when the research activities and studies occurred. This research work was carried out over the period from January 2004 to August 2010 whilst the author was working as Research Fellow in the field of digital libraries and then as a Lecturer in the Department of Design Manufacture and Engineering Management at the University of Strathclyde.

1.2 Vision

The act of distributed design information storing is a process whereby engineering or product development teams work together towards a common goal, using information, separated by distance using a variety of technologies. The information they store supports a shared understanding of the problem and affords project progress. The literature has shown that a significant amount of time is spent managing design information rather than focusing on the design task itself. Engineers spend as much as 20-30% of time searching for and handling information (Court et al., 1993; Marsh, 1997). Project information in teamwork is often poorly managed and used due to a number of factors, for example lack of time, loss of information, lack of team trust, etc. In distributed team work these issues can be exaggerated and further difficulties exist; for example, difficulties with technologies and communication, or a lack of context. In the late nineties, studies at Bath and Bristol Universities noted that no prescription or guidance on information management existed to support designers (Culley et al., 1999). The author's studies into the understanding of distributed team information storing processes show that students' information collections can often be unorganised, contain unclear information and lack context. Students find storing and sharing of design information and knowledge in distributed teams time consuming and the tools awkward to use. This can lead to poor project progress and can impact directly on the quality and success of project outputs (Grierson et al., 2004, 2006). Students require guidance on distributed information storing to improve the student experience in distributed team-based design engineering work and to enhance their use of information. In global environments, skills in distributed information management are becoming increasingly important both because of the quantity of information available and because of the ready availability of IT tools to support information management. The effects of technological developments, like virtuality and pervasiveness, will strongly affect design education (Broadbent & Cross, 2003). So far research has mainly focused on the search for and use of information with little focus on how students store and manage information and resources (Nicol et al., 2005). This thesis sets out to address this by understanding how students store distributed design information and by developing a set of Principles which in turn prepare graduates for work in a global context, equipping them with the necessary skills in distributed design information management. In a general sense, in terms of a conceptual model, intervention of the Principles would positively impact on student information storing behaviour and on outcomes related to students' satisfaction with the global experience; on their skills development and the quality of Project Memories in terms of their structure, organisation and richness of content. Additionally intervention of the Principles can possibly impact on other aspects of project performance such as reduced communications delays; equal engagement by all distributed team members; and increased shared understanding of the project problem.

1.3 Research Aims and Objectives

The thesis addresses three main Aims, each with a number of objectives. The Aims and the Objectives are listed in Table 1.1.

Research Questions and Hypotheses

The key Research Questions addressing these Aims and Objectives are presented in Table 1.2. Chapters 4 and 5 address Research Question 1; Chapters 6 and Part 1 of Chapter 7 address Research Question 2 and Research Question 3 is discussed in Part 2 of Chapter 7.

	Aims		Objectives
1.	To understand information storing behaviour of students working in distributed design team-based project work	**Ob1.**	Identify the storing issues that distributed teams experience when engaging in distributed design team-based project work
		Ob2.	Establish how students store distributed design information through a series of 'real life' case studies in the context of a *'Global Design Project'*
		Ob3.	Make recommendations for improving distributed design information storing practices
2.	Develop an approach to support enhanced distributed design information storing practice in distributed design team-based project work	**Ob4.**	Develop a method/model/tool, include consultation with users - students and academics
		Ob5.	Test and validate the application and efficacy of the method/model/tool in the context of a *'Global Design Project'*
3.	Develop and strengthen the '*Project Memory*' concept within the context of distributed team work	**Ob6.**	Review past and current positions on the '*Project Memory*' concept
		Ob7.	Make recommendations on criteria and content for a distributed design *Project Memory*

Table 1.1: Thesis Aims and Objectives

Research Questions	Objectives
1. **How do students store and share design information and knowledge in distributed design team-based project work? –** • What information content is stored? What formal and informal information is stored? What information carriers are used? What information do students value? • Where is information stored? • When is it stored? And why?	**Ob1.** **Ob2.**
Hypothesis 1 *Student information storing practices in distributed design team-based project work are currently inadequate.*	
2. **How can students be encouraged and supported to record project work in a distributed design context?**	**Ob3.** **Ob4.** **Ob5.**
Hypothesis 2 *A structured set of educational Principles and a Framework will support and improve student information storing practices in distributed design team-based project work.*	
3. **What should a *Project Memory* to support students undertaking distributed design contain?**	**Ob6.** **Ob7.**
Hypothesis 3 *Clear recommendations on criteria and content for a Project Memory developed by applying a structured set of educational Principles and a Framework will support and improve student information storing practices in distributed design team-based project work.*	

Table 1.2: Thesis Research Questions and Hypotheses

1.4 Research Methodology

Key to the research philosophy underpinning this work, is the interpretivist paradigm to provide insight and a deeper understanding of engineering design students' distributed information storing processes and experiences. In the past this type of study in the field of design has often been found to be lacking; too exploratory and anecdotal. To address this, and to provide rigour (Shah & Corley, 2006) and ensure trustworthiness relative to the qualitative research (Lincoln & Guba, 1985) undertaken as part of this work, a **Design Research Methodology** (DRM) has been adopted. Methodologies are distinguished from research methods as being more general and less prescriptive. They often consist of various research methods (Mingers, 2007). For the relationship between design, design research and design research methodology see Figure 1.1.

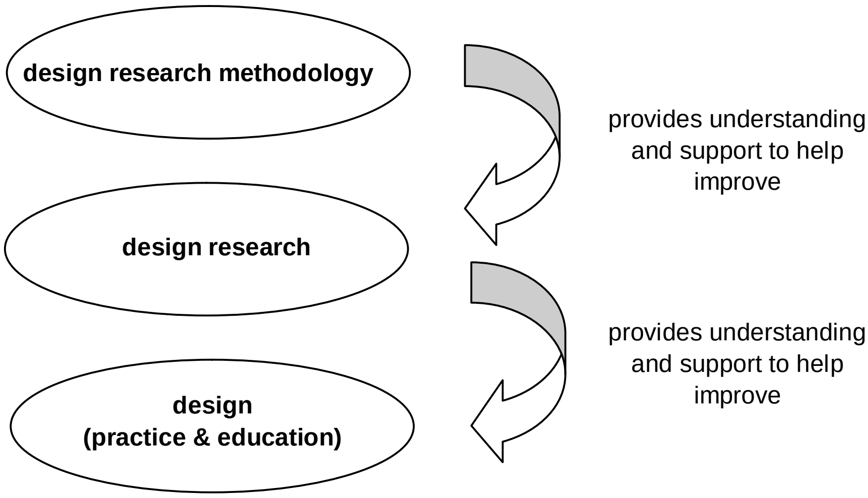


Figure 1.1: Relationships between Design, Design Research and Design Research Methodology. Source: Blessing et al. (2009, p.10)

Blessing et al.'s *Descriptive/Prescriptive Design Research Methodology* (Blessing et al., 1998) has been used for this research to add rigour through its formal and systematic approach. Following a reasonably structured process seems to lead to a greater design success whilst rigid, over-structured approaches do not appear to be successful (Cross, 2001). Blessing et al. recognised the need for a DRM to link together various (often ad hoc) aspects of design research into -

> *"....a methodology for doing engineering design research that underlines the importance of descriptive studies for the development and validation*

of methods and tools for design….using many different methods."

(Blessing et al., 1998, p.16)

This methodology's key requirement is to define the characteristics of existing processes in order that a new approach may be developed with a view to changing and improving design processes or practices. It is an appropriate methodology to use, in this case, not simply for the rigour it brings to the work but also because it provides structured direction to the research. It supports the key stages of design research, namely – the understanding of how the design process under examination actually takes place; the design of a method/model/tool (an intervention) to change the process or practice; and the validation of that intervention. It is a recognised methodology in the field of engineering design research and supports investigations into design practice in both industry and design education.

Blessing et al.'s Descriptive/Prescriptive DRM consists of 4 stages which include the examination of existing processes and an element of testing or validation of new developments. These Stages will now be detailed in the context of this thesis work -

Stage 1 - Criteria/Focus *- scoping of problem and identification of focus for work; including criteria for success.* At the early stages of the work, the literature review and earlier teaching experience helped identify the focus of the research and also determine factors and issues that would contribute to or prohibit success.

Stage 2 - Description I *– conducting of descriptive studies towards the understanding of the various issues and factors that influence the focus of investigation.* At this stage, *Descriptive Studies* were required to identify influencing factors without having an effect on the processes being studied. The role of the researcher at this point was one of analyst/observer rather than interventionist. Over a period of two years 3 Studies were undertaken examining 6 Cases of distributed design information storing in student team-based design projects. All studies took place in the context of the teaching classroom. Distributed design information stored by student teams was quantified and analysed supported by questionnaires to identify issues. Semi-structured Interviews were used to explain phenomenon and validate findings.

Stage 3 - Prescription *– based on the outcome of the descriptive studies and on assumptions and experience of an improved situation, a method or tool is developed to encourage and support the issues identified at Stage 2.* Findings and recommendations from the Case Studies informed the *Prescriptive Stage* indicating how distributed design information storing could be improved through change, i.e. the design and development of a new approach through the use of a method, model or tool. A set of guiding **Principles for d-DIS** were developed and the existing **Project Memory Concept** was further developed. A series of Principles' Focus Groups with students and academics supported this stage.

Stage 4 - Description II *- otherwise referred to as the Validation and Testing Stage. The developed method/tool is applied and a further descriptive study undertaken to establish if the problem initially outlined has been supported.* The final stage, in this case was less about description and more about validation. It involved the testing of the Principles and Framework with students in the context of a Global Design Project, and validation through Questionnaires and Semi-structured Interviews.

Figure 1.2 provides an overview of this PhD's Research Methodology used at each of the Stages, based on *Blessing et al.'s Descriptive/Prescriptive Methodology.*

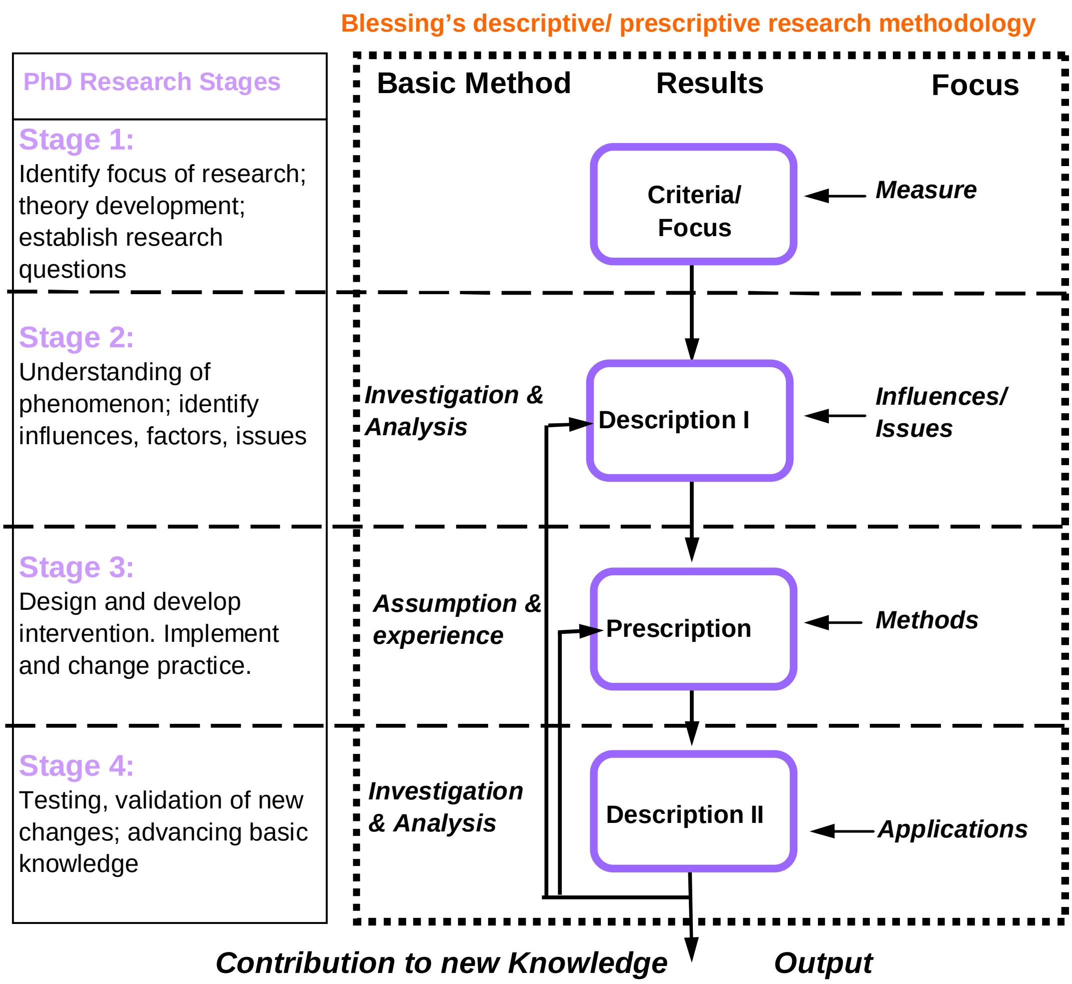


Figure 1.2: PhD Research Methodology. Based on Blessing et al. (1998, p.44)

It has been acknowledged that all stages of this methodology cannot be expected to be executed in depth, to the same level, on every research project, particularly in PhD work, for example where time limitations on descriptive studies may cause restrictions (Blessing et al., 1998). This work places greatest emphasis on Stages 2 to 3, resulting in four contributions to new knowledge; see Section 1.5. It should be noted that design research studies often encounter limitations due to the complexity of design and the interconnectivity of its various issues and influences. Added to this is the uniqueness of each design project. The use of a DRM affords the flexibility to address this. In addition to using a recognised DRM, to further ensure a rigorous approach, a range of research methods were used to collect, analyse and report data; and to validate the proposed interventions; see Table 1.3.

Research Methodology (adapted from Blessing et al.'s DRM)	**Research Methods**	**Contribution**
STAGE 1 *Criteria/ Focus*	Problem Defining Literature Review	Issues with information storing in distributed student team-based project work
STAGE 2 *Description I –* Identifying issues	Case Studies Content Analysis Data/Archive Analysis Student Reflection Questionnaires Semi-structured Interviews	
STAGE 3 *Prescription –* Developing Methods/Tools/Models	Coding Categorising & Clustering Visualisation/Mindmaps Focus Groups	Recommendations for Information Storing Guiding Principles and Framework
STAGE 4 *Description II –* Application and Testing/ Validation	Implementation Testing Content Analysis Data/Archive Analysis Questionnaires Semi-structured Interviews	Guiding Principles and Framework Project Memory Criteria and Model

Table 1.3: Thesis Research Methodology, Methods and Contribution

The research methods included the **Case Study Method**, used to gain an understanding of student teams' design practice and processes and emerging issues at the *Descriptive* stages (Yin, 2003); **Data/Archive Content Analysis**, as a systematic, replicable technique for establishing content categories based on rules of coding (Miles and Huberman, 1994; Weber, 1990); **Questionnaires** and **Student Reflection** to gain insight into student information storing behaviours and **Semi-structured Interviews** to validate findings. **Focus Groups** were also used to further develop proposed interventions and validate experiences. **Coding, Clustering** and **Visualisation/Mindmaps** drew out descriptive findings (Miles & Huberman, 1994). These will be discussed in greater detail in Chapter 3 - Data Collection and Analysis Methods; in Chapter 6 - Development of a set of Guiding Principles and in Chapters 7 & 8 - Testing and validation of the Principles and Project Memories.

1.5 Research Framework and Contribution to new Knowledge

The overall Research Framework relates the key research activities to the 4 stages of the DRM, outlined in Figure 1.3.

This thesis contributes to new knowledge in a number of ways (see also Table 1.3) -

1. It offers a clearer **understanding of the information that engineering design students store** when carrying out distributed design project work. It does this by presenting the results and findings of six Cases into *"how, what, where, when and why students store distributed design information"*.
2. It makes a series of **Recommendations** to support the issues student teams experience in distributed design information storing.
3. It offers a set of **guiding Principles and a Framework for distributed design information storing** which will support students' storing and sharing of information and knowledge and improve the student experience in distributed team-based engineering design work.
4. It updates the research area on **Project Memories** and contributes further to this research area through the development of a **Project Memory Model** to support distributed design information storing.

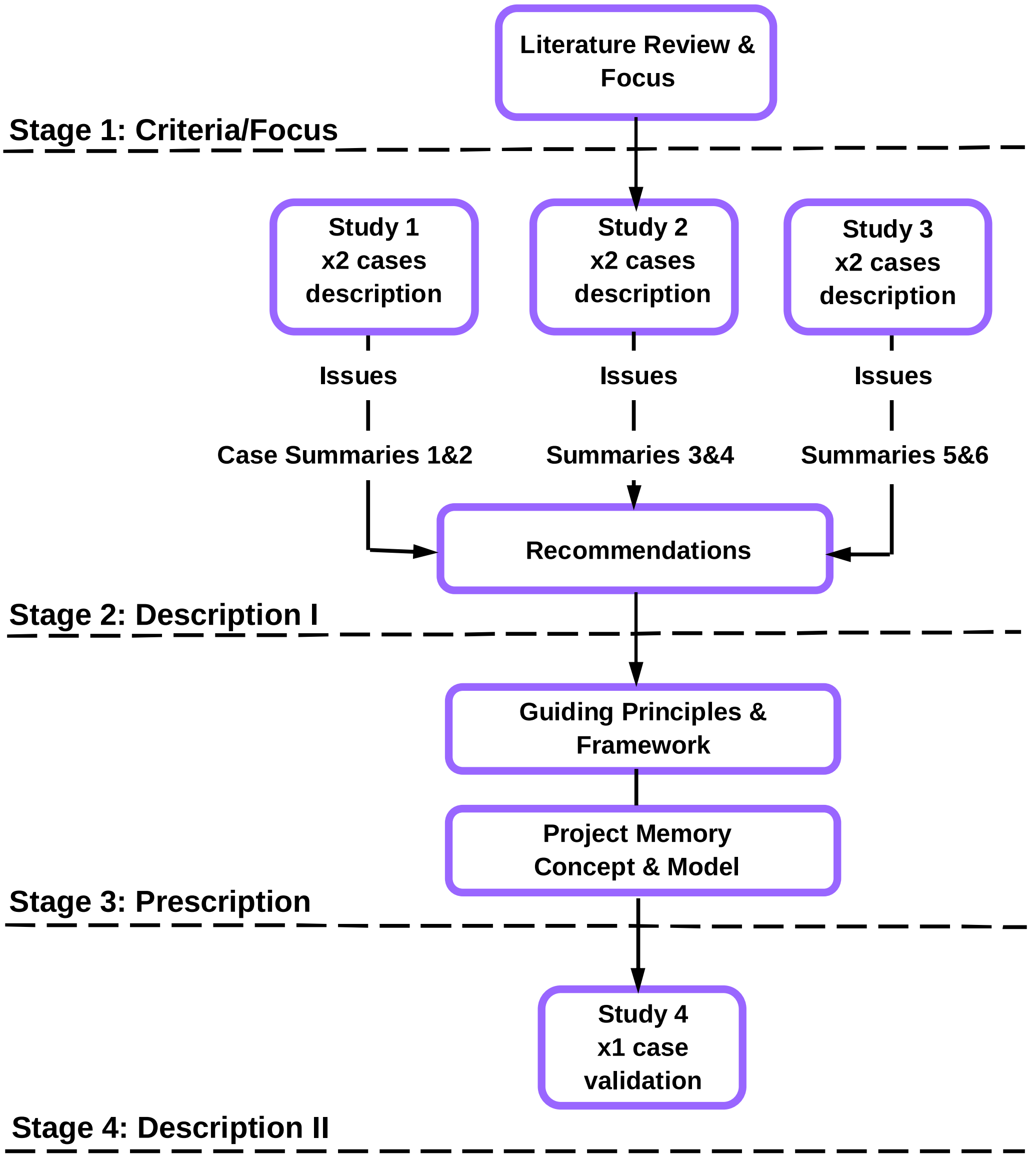


Figure 1.3: Research Framework

1.6 Thesis Structure and Map

This Chapter concludes with the presentation of the Thesis Structure and Map, identifying the chapters in relation to the stages of the DRM used to give direction to the work. It includes a timeline indicating when the various activities and studies of the work occurred; see Figure 1.4.

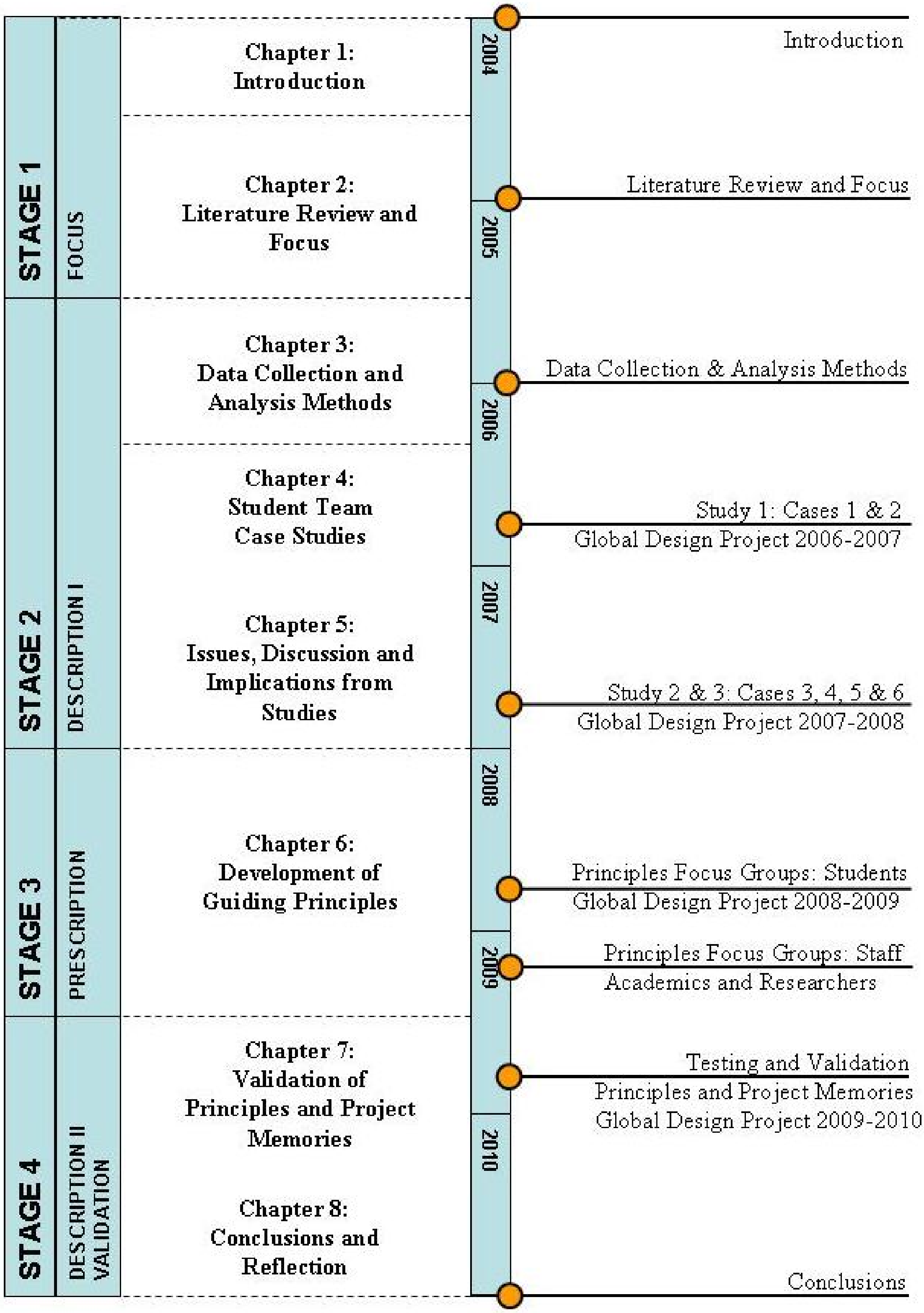
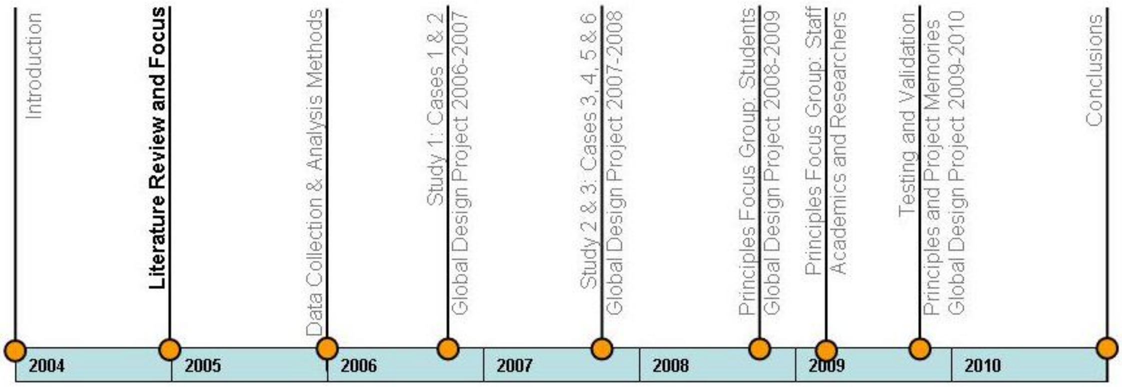


Figure 1.4: Thesis Structure and Map

2 Literature Review and Thesis Focus



2.1 Introduction and Literature Map

This Chapter will outline Stage 1 of the work, the *Thesis Focus*. The Chapter covers a Review of the Literature by referring to prominent writings in the fields relating to the thesis research, see Figure 2.1. Section 2.2 outlines the nature of distributed design and distributed teams; Section 2.3 reviews the concepts of data, information and knowledge with an emphasis on engineering information management and information storing. The concept of 'Memories' is reviewed in Section 2.4. Here the author's thinking on *Project Memories* is drawn from the literature on Organisational Memories (OM), Corporate Memories (CM) and Project Memories (PM). Section 2.5 concludes the Literature Review with an overview of the educational context, relevant to the work.

The Review of the Literature is narrative in its approach, suited to work of an interpretative nature. It gives an initial impression of the research fields and is intended to be less focused and more wide-ranging in its scope than a systematic review. Figure 2.1 maps the areas of Review: Engineering Information and its Management, with a particular interest in the storing and sharing of information and an examination of Formal and Informal information; Distributed Design, with an overview of the issues experienced by distributed teams; and an overview and discussion of the concept of 'Memories'[1], online spaces where teams store and share information, in their various forms. The review would not be complete without

[1] The concept of 'memory' is used in the metaphorical sense of organisational memory in the thesis.

reference to the literature in key-related educational areas: project-based learning, reflection and the students as a global designer. Gaps and issues identified from the literature contributed to the Thesis Focus, which is presented at the end of this Chapter, and helped define the thesis research questions.

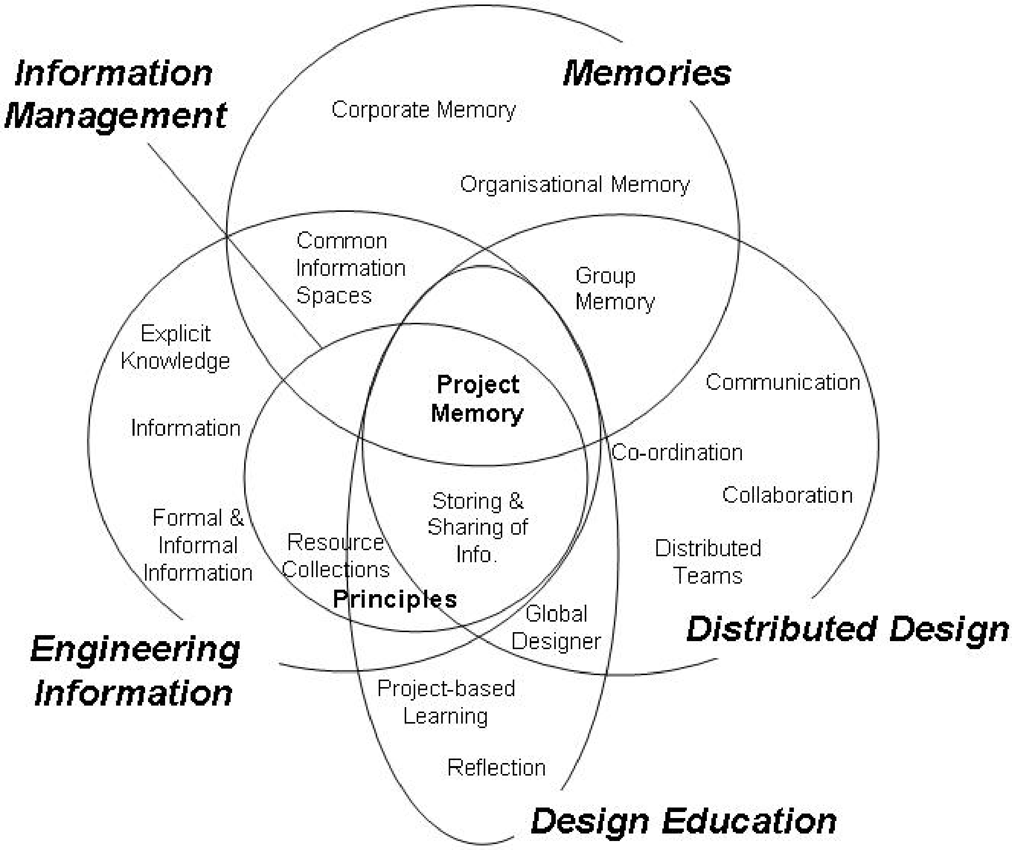


Figure 2.1: Map of Review of the Literature

2.2 Distributed Design

2.2.1 The Nature of Design

> *"Design is an engineering activity that:*
> - *affects almost all areas of human life;*
> - *uses the laws and insights of science;*
> - *builds upon special experience; and,*
> - *provides the prerequisites for the physical realisation of solution ideas…."* (Pahl & Beitz, 1996, p.1)

It is a social activity (Bucciarelli, 1984) which depends on the successful communication and collaboration of all members of the design team in order to achieve a solution to a set problem. It can be viewed as a process and a systematic series of steps originating from a market need through to the realisation and commercialisation of a product (Pugh, 1991). See Figure 2.2. The Global Design Projects used as case studies in this work follow this design process from 'market' to 'detail design' and prototype stage.

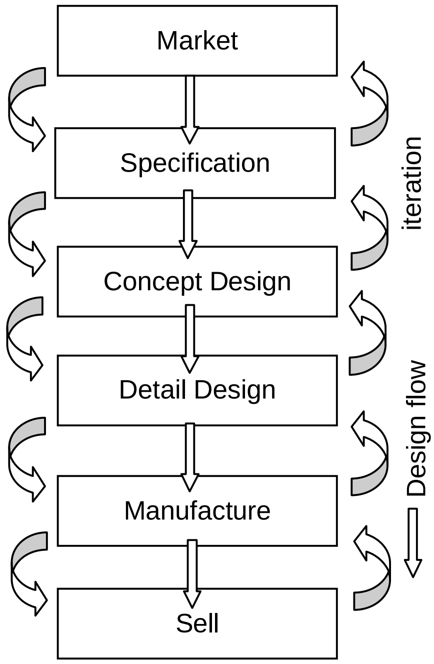


Figure 2.2: Design Process Stages. Based on Pugh (1991, p.146)

Hales (1993) describes engineering design as the process of converting an idea or market need into the detailed information from which a product or technical system can be produced. This design process is a complex and information intensive activity complicated further by the ever increasing global market and a greater need to carry out design distributedly. Co-ordination of information is seen as central to the design process and crucial to the success of product outcomes.

2.2.2 The Nature of Distributed Design

Distributed design is the practice of design by members of a team separated by geographical distance, with the added complexity of technology, social and cultural differences. It manifests itself in two modes – *synchronous* working (at the same time) and *asynchronous* working (at different times) and is supported by various information, communication and collaboration technologies; see Table 2.1.

	Same Place (co-located design)	**Different Place (distributed design)**
Same Time (synchonous)	**Face to face team (f2f)** Projectors, bluetooth/ infra-red/ wireless, electronic whiteboards	**Distributed team in space, 'real' time** Internet, webcams, video conferencing, virtual whiteboards, groupware
Different Time (asynchonous)	**Different time, same space** Internet, webcams, electronic whiteboards, groupware	**Distributed team in space and time** Internet, groupware, web-based shared workspaces, virtual/electronic whiteboards, email, scanners, digital cameras

Table 2.1: Place Time Grid. Based on Skyrme (1999, p.85)

As the time difference increases, realisation of the asynchronous mode becomes more difficult due to issues such as –

- Co-ordination breakdowns: Engineering design is information-intensive and comprises many complex activities making the managing of people, tasks and information over distances especially difficult, and at times confusing. Information can be lost; difficulties can emerge in finding information; tools and technologies can exacerbate the situation (Carmel, 1999; Herbsleb & Mockus, 2003; Hinds & Mortensen, 2005).
- Communication breakdowns: In a distributed setting, occurrences of communication breakdowns can be high due to the lack of richness and interactivity when compared to face to face (f2f) communication. Distance leads to reduced communications or to people experiencing problems with media that cannot substitute for f2f communications as they lack the necessary richness and interactivity (Cramton, 2001; Chudoba et al., 2005). Time zone differences reduce the opportunities for real time collaboration and reduce its intensity as communication response time increases considerably when working hours at remote locations no longer overlap (Sarker & Sahay, 2004; Smith & Blanck, 2002). It may take much longer for answers to be returned to remote sites.

Communication breakdowns often lead to silence which in itself can have multiple meanings and further contributes to confusion.

- Different skills and training or mismatches in IT infrastructure: Difficulties in collaborating can often be attributed to differences in skills, expertise and technical infrastructure which further raise the barriers for information and knowledge transfer between remote sites. Unequal skills at local sides can lead to lack of motivation and slowing of collaborative efforts (Sarker & Sahay, 2004; Oshri et al., 2008).
- Differences in culture, background and experience: These differences can aggravate issues of interaction and understanding (Kumar et al., 2005) which in turn leads to a greater chance of misunderstanding (Cramton, 2001; Olson & Olson, 2004). Cultural differences can include language, values, working habits and assumptions related to particular cultures. Experience can also relate to expertise, with a difference in levels of expertise potentially contributing to difficulties in the asynchronous mode. Differences in culture, background and experience can often lead to unhealthy subgroup dynamics (Hinds & Mortensen, 2005).
- Lack of understanding of counterparts' context: In distributed working many of the contextual cues that support team work are missing. Global teams need to be aware of their remote partners' situation and environment and to share more contextual information. Distributed workers find sharing of contextual information time consuming and uninstinctive; however, people like information that is rich in contextual cues, involving sequence and causality, for example stories (Davenport & Prusak, 1997; Perry et al., 1999; Cramton, 2001).
- Lack of trust: Establishing trust over different time zones and locations is difficult and challenging. Geographic distribution tends to reduce the amount of time that distributed workers will be in communication with each other which is therefore likely to hinder the development of trust, leading to greater chance of communication and co-ordination breakdowns (Jarvenpa et al., 1998; Holton, 2001; Kiesler & Cummings, 2002).

Many of these issues will be discussed later in the thesis in relation to engineering design students' information storing practices and experiences.

With the increasing globalisation of new product development, globally distributed collaborations and distributed teams are becoming commonplace in industrialised organisations (Malhotra et al., 2001; Gibson & Cohen, 2003; Sheppard et al., 2004; Hinds & Mortensen, 2005). Distributed working affords several benefits -

> *"Distributed collaborative teamwork, empowered by state of the art information and communication technology, promises more efficient work processes, reduced travelling needs and increased opportunities for personal interactions in many different fields of work. Specifically, collaborative work between geographically distributed teams of engineers and designers has the potential of cutting lead times in product and production development, thereby reducing the cost and increasing the quality of the final product.* (Johanson & Törlind, 2004, p.355)

Researchers agree there is a need for further guidance and support for distributed team work (Duarte & Snyder, 1999; Jarvenpaa & Leidner, 1999; MacGregor, 2002).

2.2.3 Distributed Teams

The advent of information and communication technologies (ICT) over the past years has enabled the development of the design team, from collocated working, in the same place at the same time, to distributed working, see Figure 2.3. See Table 2.2 for definitions of the design team. It should be noted that the terms *'distributed'*, *'global'* and *'virtual'* are often used interchangeably in the literature.

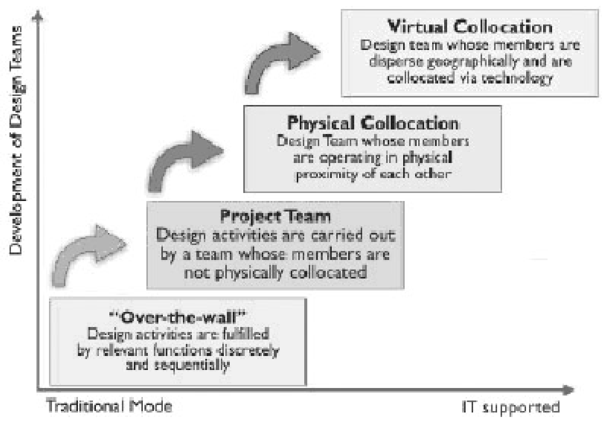


Figure 2.3: Development of Design Team. Source: Sharifi & Pawar (2001, p.183)

Engineering/ Design Team	Explanation
Collocated	These teams are comprised of individuals who work together in the same physical location and are culturally similar.
Virtual	These teams are comprised of individuals who have a moderate level of physical proximity and are culturally similar. For example, located in the same building but on different floors or located in different parts of the same country.
Distributed (Global)	These teams are comprised of individuals who work and live in different countries and are culturally diverse. They are often referred to as Global Teams.

Table 2.2: Design Teams. Based on McDonough III et al. (2001, p.111)

Distributed teams afford a valuable mechanism to bring together geographically and temporally dispersed team members to work on common tasks. In the context of industry their effectiveness has been shown to include (but not exhaustively) (Ganguli & Mostashari, 2008) –

- flexibility and dynamism, unlimited by travel and traditional schedule;
- rapid response and effectiveness to continual change;
- expansion of the pool of expertise; and,
- reduction in time to market.

Also, of particular interest to this work,

- the provision of organisations with information and knowledge repositories of team problems and solutions (Walsh & Ungson, 1991; Lewis, 1998).

Limitations for distributed teams include –

- barriers in information flow and transfer (Cramton, 2001; Rosen et al., 2007);
- loss of innovation potential (Lojeski et al., 2006);
- possible decrease in productivity due to insufficient communication and interaction (Arnison & Miller, 2002).

Early studies on distributed teams tended to be limited to drawing comparisons between the two forms of teams, collocated and distributed, in terms of communication, collaboration, co-ordination, leadership, social issues, conflict and knowledge transfer. However the research on distributed teams is increasingly available. It is beyond the scope of this thesis to give a comprehensive scoping of distributed teams beyond the references above, however, three extensive reviews of virtual teams (VT) exist – two reviews on the state of the literature and future direction (Martins et al., 2004; Powell et al., 2004) and a review of VT empirical research (Hertel et al., 2005). In the past decade there has been a shift to an exploration of the extent to which 'distributedness' affects the function of VTs (Driskell et al., 2003) with a focus on communication, but there is still little research on techniques to improve the transfer of information and knowledge in VTs (Ganguli & Mostashari, 2008).

2.2.4 Effective Distributed Design

Effectiveness of distributed design is impacted by a number of key concepts – communication, co-ordination, collaboration and co-operation, see Figure 2.4 (MacGregor, 2002). These are affected by socio-cultural (language and culture) issues and temporal distance (time zones) making the complexity of managing distributed teams higher than in traditional ones (Herbsleb, 2007).

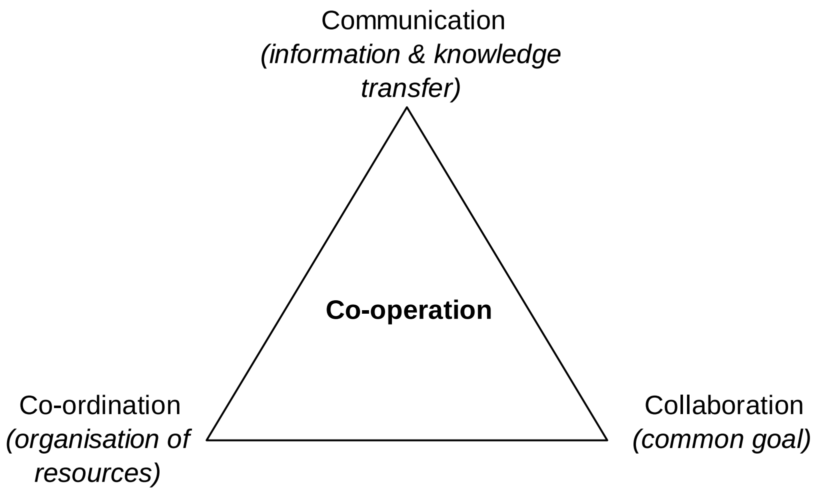


Figure 2.4: Co-operative Triangle for Effective Distributed Design. Source: MacGregor (2002, p.19)

Finally, key to distributed collaborations is a shared understanding of project goals and work processes in order to co-ordinate work towards a common outcome. A shared understanding has a number of benefits, including team satisfaction and motivation; efficient use of resources and effort; reduction in frustration and conflict

(Hinds & Weisband, 2003). Information sharing is a fundamental element of shared understanding, see Figure 2.5.

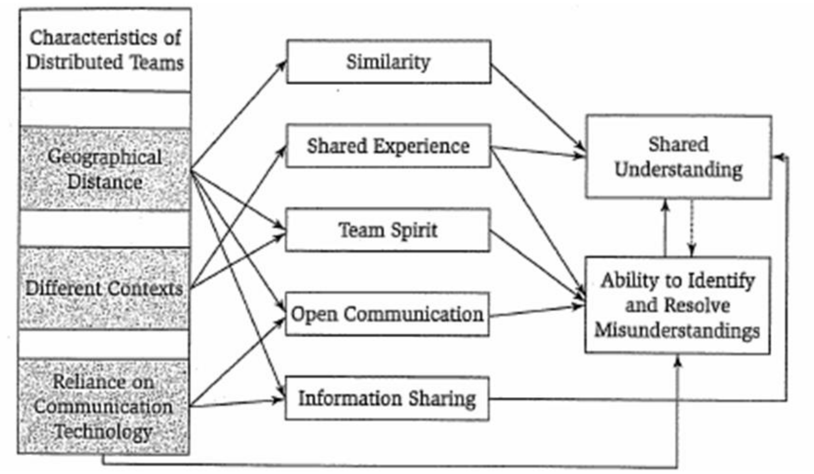


Figure 2.5: Effects of Distributed Team Characteristics on Shared Understanding. Source Hinds & Weisband (2003, p.26)

2.3 Engineering Design Information

Engineering design is an information intensive process reliant to a great extent on information to achieve its goals (Baya, 1996; Ward, 2001). It results in a process heavily dependent on information and knowledge to achieve its core activities. Therefore improved processes and better product outcomes can be realised through efficient and effective utilisation of information and knowledge resources for engineering design (Hicks et al., 2002). The following section reviews engineering information and its management, setting the context by first introducing empirical studies in engineering design.

2.3.1 Empirical Studies in Engineering Design

Overview

The need for a greater understanding of the processes and practices of engineering designers has necessitated the rise of empirical studies in engineering design over the last four decades, pioneered by Eastman in the 1970s (Eastman, 1970). Early studies include the work of Hales who accounted for the way engineering design participants spent their time engaged in different design activities (Hales, 1987); Bucciarelli's ethnographic studies in industry (Bucciarelli, 1988); detailed summaries of engineering design empiricism (Subrahmanian, 1992); and accessing of engineering design information (Court et al., 1997). These studies not only provide an enlightening picture of engineering practice at the time but can offer a sound basis for the undertaking of further engineering design studies. Over the past decade, empirical studies have gained more importance and are becoming more commonly used in engineering design research. This area of research has widened its view from prescribing to describing design activities (Foltz, et al., 2002). These empirical studies cross both industrial and academic fields. For example –

Industrial – The study of tacit aspects of team work in design teams at Rolls Royce (Baird et al., 2000); the use and re-use of experience in engineering design by novices and experts (Ahmed, 2001); a study of ten engineers in industry using and organising information (Lowe et al., 2004); distributed design support processes (MacGregor, 2004); the investigation into the content of engineers' logbooks (MacAlpine et al., 2006); issues of information management in ten engineering SMEs (Hicks et al., 2006); the management and organisation of mechanical engineers' personal computer files (Hicks et al., 2008); exploration into engineers' use of information in high-tech international firms (Allard et al., 2009); and the study of diary content of engineers (Wild et al., 2010).

Academic – Longitudinal studies of freshmen and senior students' design behaviours (Adams et al., 2003); the examination of formal and informal information content of design documents of students studying mechanical engineering (McAlpine et al., 2009); investigation into the information seeking behaviour of twenty-six engineering graduate students (Kerins et al., 2004); and the examination of product design engineering students' searching behaviours in a digital library (Wodehouse et al., 2006).

As the need to understand engineering practice becomes more important, industry and academic studies have much to inform each other. Ahmed and Lauche present extensive reviews of empirical research in engineering practice, and information and knowledge management, respectively (Ahmed, 2007; Lauche, 2007). There are many challenges and issues involved with undertaking empirical studies in engineering design in industry. These are covered well by Ahmed and Wallace (2002). When carrying out research into design information and knowledge there are further challenges to consider, such as the distributed, international and multi-cultural nature of the design process; the wide range of information representations; commercial sensitivity and confidentiality; timescales and the complexity of the artefacts and the teams (Wild et al., 2007).

Previous and Current Approaches to Empirical Studies

Many of the methods used by engineers to conduct empirical studies have been adopted directly from social science (Cross, 2001). Methods include various forms of observation, experiments, surveys, questionnaires and interviews. For example, McMahon supports participatory observational studies as they can give maximum insight into the issues under observation. However such studies have been found to be difficult to conduct, hard to replicate, and are often conducted over long periods of time (McMahon, 2002). Direct observation as the primary and only research method has been ruled out in this thesis due to difficulties in directly observing all members of a distributed team. Such a method would also have conflicted with teaching commitments during class time. Efforts were made to minimise the impact the study might have on classes. Experiments, as used by Tang (1991), are also valuable in this area of research, however they can often be found to be ‘artificial’ and divorced from the real design practice being studied. Experiments were avoided in this study in part to maintain fairness across all students in classes. A control group might be seen to advantage or disadvantage particular students.

Court produces insightful findings and meaning through the use of an extensive survey, and questioning, in his PhD studies into how engineers obtain information. (Court, 1995) Surveys, as a main method, were not considered within this thesis due to the small numbers involved in ‘observable’ classes and the need for depth of inquiry. Surveys, using specific terminology within specialist fields, can also be open to misinterpretation and misunderstanding. Content analysis of documents or archives is another method used by others. Radcliffe & Lee use content analysis to study the design activities of mechanical engineering students, proving a positive correlation between the quality of a design and the degree to which students followed logical sequential design processes (Radcliffe & Lee, 1989). McAlpine compares the information content in informal logbooks and formal project records generated by six trainee mechanical engineers, creating a new information classification schema (McAlpine et al., 2009).

Case Studies are also a common method of analysing and presenting findings from empirical studies. For example, Crabtree et al. (1997) use case studies to present activities and problems in collaborative design; MacGregor (2003, 2004) studied the distributed working behaviours of employees in order to prescribe a framework for improved distributed design practice.

2.3.2 Data, Information & Knowledge Definitions & Relationships

Information is a difficult concept to define compounded by the fact that it is so intrinsically interrelated to the other concepts of data and knowledge, indeed often used synonymously with these two concepts (Hicks, 1993; Court, 1995; Hicks et al., 2002; Huet, 2006). Numerous definitions for data, information and knowledge exist (Benyon, 1990; Tomiyama, 1995; Ahmed et al., 1999; Stenmark, 2001) including an extensive review by Court (1997) and definitions by Hicks et al. (2002) in the context of engineering design.

The British Standards Institution define these concepts, simply, as –

- **Data** - *"facts, statistics, that can, frequently, be analysed to derive information"*;
- **Information** - *"the descriptive content of a message which allows a change through interpretation"*; and,
- **Knowledge** – *"a cumulative understanding of the information and data in the specific context of an application"*. (British Standards Institution, 2003, online)

The literature often presents the relationships between the concepts hierarchically, best known as the Data/Information/Knowledge (DIK) Model (Bellinger, et al., 2004 (see Figure 2.6); Marsh, 1997; Davenport & Prusak, 1998; Choo et al., 2000). Tuomi (1999) makes the argument for the reverse; that knowledge must exist before information can be formed and before data can be measured to result in information, also often referred to as the KID Model.

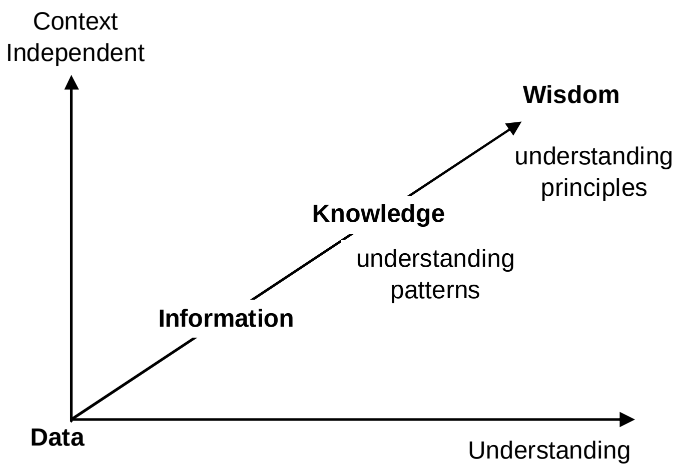


Figure 2.6: DIK Model. Source: Bellinger et al. (2004, online)

Early work on knowledge management did not sufficiently separate information from knowledge (Nonaka & Takeuchi, 1995). Confusion further arises because definitions often refer the concepts to each other. Data is described as information in numerical form (Benyon, 1990); information is described as data within a context (Court, 1995); information is knowledge which can be transmitted without loss of integrity (Kogut & Zander, 1992); knowledge is information within people's minds (Davenport & Marchand, 1999); and knowledge elements are conveyed as information which can be explicitly defined (Boston, 1998). As a result, the definitions of data, information and knowledge can become inconsistent when examined in relation to one another (Ahmed et al., 1999). Quintus (2000) refers to the Iceberg Model noting that only explicit knowledge can be recorded; tacit knowledge remains in the mind and implicit knowledge cannot be recorded and codified in any format. Tang et al. (2008) neatly demonstrate in Figure 2.7, the visible and hidden forms of information and knowledge. Only those elements which are visible can be stored and shared in a repository or shared information space and will be examined by the author.

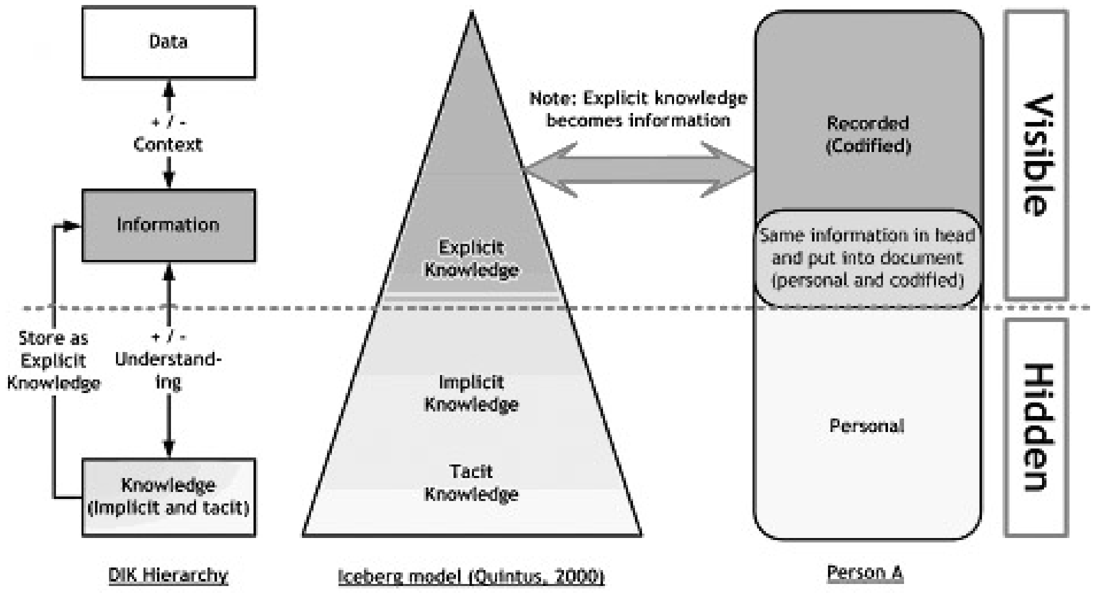


Figure 2.7: Information and Explicit Knowledge. Source: Tang et al. (2008, p.4)

For the purposes of this work, the author views information as factual and knowledge to be more about beliefs and that knowledge can be regarded as information when explicitly represented -

> *"Information is something that can be pointed to, found, lost, written down, accumulated, compared and so on, whereas knowledge is harder to transport, receive or quantify.* (McMahon et al., 2004, pp.309-310)

> *"Explicit knowledge…..can be articulated and stored externally as information. It includes descriptions about how to undertake the stages and steps of the design process…This information is stored in reports, standards and manuals and is easily retrieved. "*
> (Wallace et al., 2005, p.332)

Choo (1996) notes the use of information is the selection and processing of information which then results in new knowledge or action. It would be hard to form new knowledge and understanding without stored and shared information in distributed project work.

2.3.2.1 Formal and Informal information

There has been a shift in engineering design practice and education from a *product-related focus* to a *practice-related focus* with the need to record more informal information to support decision making (Hicks et al., 2002; Grierson et al., 2006; McAlpine, 2009). **Formal information** and knowledge (often referred to as 'hard') is the primary work product of the worker and is easily and routinely captured. It is factual and informative. **Informal information** and knowledge (often referred to as 'soft') is created in the process of producing the formal results. It is more practice-oriented and gives context to the formal information.

Modern engineering practice taking place in distributed environments necessitates the sharing of informal as well as formal information (McMahon et al., 1993). Formal information alone is not sufficient for accurate project records. The meaning of formal information could be lost if not supported by informal information (Huet, 2006; Conway et al., 2008). Fruchter and Yen (2000) suggest that by capturing informal design activities in informal media types, design rationale and design decisions then become explicitly stated in project archives. These can be shared in real-time or revisited in the future.

Several studies have made the distinction between formal and informal information and knowledge in engineering design (Wall, 1986; McMahon et al., 1995; Fruchter & Yen, 2000; Lowe et al., 2003) but it has only been in the last decade that definitions are beginning to become formalised and accepted (Culley & Allen, 1999). Hicks builds on the work of others to define formal and informal information as structured or unstructured with both sharing common mechanisms for exchange – textual, pictorial and verbal modes (Hicks et al., 2002). This research takes another view when examining the formal and informal information content stored by distributed teams: identifying information content categories based on *product outputs* and *practice-related outputs*. Wallace et al. (2005) also make the case for the distinction between product and process knowledge. This is discussed further in Chapter 3.

2.3.2.2 Definitions for use in this research

From the preceding review of the work of others the following definitions will be used in this work –

- ***Data*** – facts or statistics from which information can de derived.
- ***Information*** – something that can be explicitly told or recorded containing data. Information can be both formal and informal.

- ***Formal Information*** - information identified as more *product-related*; it is more factual and declarative and is about the outputs and results. See Chapter 3 for more detail.
- ***Informal Information*** - information identified as more *practice-related,* produced as a result of generating the outputs and results. See Chapter 3 for more detail.
- ***Knowledge* –** an understanding of the information and data in a given context, dependent on experience and beliefs.

2.3.3 Engineering Information Management

Studies have shown that engineering information is fundamental to the process of design development (Minneman, 1991; Bucciarelli, 1994; Henderson, 1999) and that effective engineering management is regarded as fundamental to the successful operation of engineering organisations (Coates et al., 2004). Engineering information management is considered a sub-set of engineering management and it -

> *"… can be considered to involve adding value to information by virtue of how it is organised, visualised and represented;…"*
>
> (Hicks, 2007, p.233)

Due to their high dependency on information, companies can gain a competitive advantage and significant improvement in organisational performance and operating efficiency by utilising information and knowledge systems (Hicks et al., 2002; Chaffey & Wood, 2004; Hicks et al., 2006). The importance and need to record and maintain organisational information and knowledge has increased over recent years with the shift from product delivery to through-life service support in engineering companies (McMahon et al., 2005) but the issues are many –

- the challenge of the ever-increasing volume of information in engineering design organisations coupled with little available help for organisations (Zhao et al., 2008);
- the need to gather task-related information from a wide variety of sources (Cross & Cross, 1995);

- the requirement in modern engineering environments for engineers and designers[2] to communicate and share information across extended distances (Court et al., 1997); and, in distributed team work problems relating to information access and information acquisition are the most common (Crabtree et al., 1997);
- distributed collaborations tend to be of a multi-disciplinary nature (Zavbi & Tavcar, 2005);
- the need to share informal information as well as formal information (McMahon et al., 1993; Grierson et al., 2006; Conway et al., 2008);
- the high amount of time taken to manage information. This area has been well researched: with 20-30% of time searching for and handling information (Court et al., 1993); 24% of a designer's time is spent sourcing or locating relevant information and knowledge (Marsh, 1997); and, 20-40% of time spent searching for and accessing information (Culley et al., 1992). Some earlier studies report even higher estimates: Rzevski suggests that as much as 70% of time is taken up with tracking down information (Rzevski, 1985); and, engineers spend as little as 15% of time doing analytical tasks and rest of time is spent negotiating and locating information (Bucciarelli, 1984; Subrahmanian, 1992).

Studies in information and knowledge management for design at the Universities of Bath and Bristol found designers to be poor at managing information and knowledge and that there existed no prescription or guidance on information management for designers (Culley et al., 1999). Additionally, many support systems, tools and methods have been developed for engineering design but not so many have been designed with the requirement of engineers in mind (Lowe et al., 2004). There needs to be an understanding of how engineers manage information and still little is known about the use of information and documents by engineers (MacMahon et al., 2004). However, this is changing. Recent in depth studies in information use include – logbook studies (McAlpine et al., 2006); the information stored by students in distributed project work (Grierson et al., 2006); the information content in design

[2] The author makes no difference between the terms *'engineers'*, *'designers'* and *'design engineers'*.

documents (McAlpine et al., 2009); studies of engineers' diaries (Wild et al., 2010); and the use of email in engineering organisations (Wasiak et al., 2010).

Work on Principles in Engineering Information Management

Hicks argues that there are many tools and methods for improving particular aspects of information management but there is a lack of support for improving information management *per se*. He proposes a set of Principles for Lean Information Management to support improvement of engineering information management through the premise that information management can add value by virtue of how it is organisation, visualised and represented. Hicks examines the potential benefits of lean thinking and then applies this to information management in order to characterise the nature of waste and establish five principles of: value, value streams, flow, pull and continuous improvement in the context of information management (Hicks, 2007).

Even more recently, McMahon and others have been addressing the lack of support for engineering information management through the development of a set of Principles for engineering management, derived from McMahon's experience of earlier empirical and theoretical observations and the work conducted within the Knowledge Information and Management (KIM) Grand Challenge Project[3] (McMahon et al., 2009). On the KIM Project a team of over seventy academics and researchers from 11 universities looked at the information and knowledge management challenges associated with through-life product support. A set of eleven Principles for the Through-Life Management of Engineering Information has been a major output of this three year programme with their application currently being evaluated (Caldwell, et al., 2009). The key motivation behind the Principles was to enable the reuse of today's information to the advantage of tomorrow's business success. If current information is preserved, organisations will be able to reuse that information to inform service provision, product upgrades and the design of future products and services. The Principles can be viewed as a mechanism that, if applied to information management practices, could mitigate risks, such as unavailable or

[3] www-edc.eng.cam.ac.uk/kim

misinterpreted information; and make information more accessible, usable and reusable.

2.3.4 Information Storing

Davenport identifies information storing as one of six distinct but related information management processes (Davenport, 1993). Information storing is central to Choo's Information Management Cycle (see Figure 2.8) and whilst a lot of work has been carried out on information processes such as information retrieval (Fidel et al., 2000; Poltrock et al., 2003) and information seeking (Hertzum & Pejtersen, 2000), less has been researched on information storing practices themselves. The need for support for engineering information management today is even more critical, with users more inclined to store large amounts of information due to the cost of storage decreasing; storage capacity increasing; and improvements in search technologies (Hicks et al., 2008).

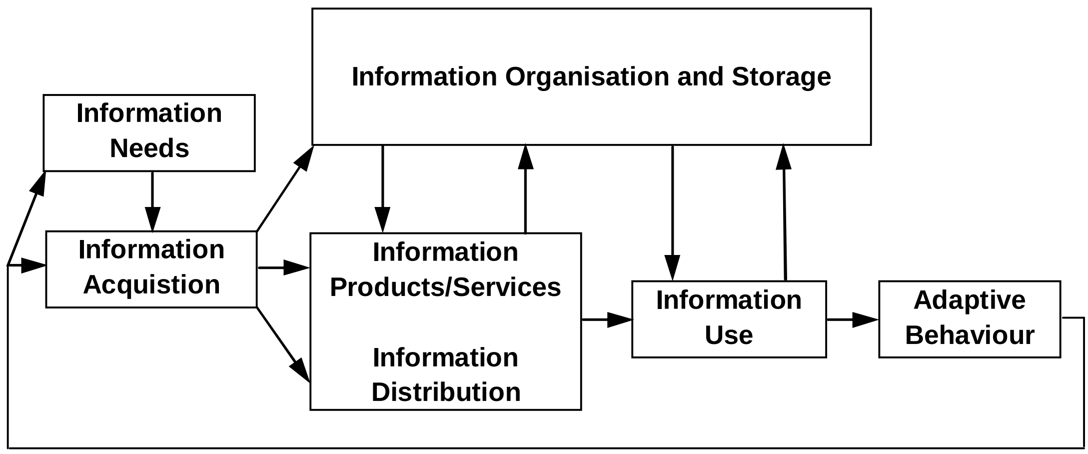


Figure 2.8: Information Management Cycle. Source: Choo (1995, p.24)

2.3.5 Engineering Information Systems

There are many commercial and bespoke tools currently available to support information management – workflow tools; data management systems (DMS); electronic data management tools (EDM); product data management tools (PDM); product lifecycle management tools (PLM) to note a few; but it is the online spaces where information is stored that is of interest in this work. These are sometimes also referred to as shared information spaces (Davis et al., 2001) or common information spaces (Bannon & Bodker, 1997). Without extensively reviewing these systems, which is beyond the scope of this work, they have been shown to support collaborative learning and distributed team working in engineering design (Ion & Neilson, 1997; Sclater et al., 2001; Sikkel et al., 2002; Nicol & MacLeod, 2004). A shared workspace, when used in the context of team projects in engineering design, operates as a central access point and repository for working documents that can be manipulated by team members at anytime and from any location. Nicol & MacLeod (2004) note that this creation and sharing of task relevant documents in a shared workspace supports design and project learning. This work regards a distributed team's shared workspace as a *Project Memory* (PM) which is afforded more attention in the following below.

2.4 The Concept of 'Memories'

This section will discuss some of the concepts of 'memory' relevant to this thesis. It should be noted that the term 'memory' is to be used in the metaphorical sense of organisational memory (OM), discussed further below. The author regards a PM, along the same lines as Conklin's thinking (Conklin, 2001), as an external technology-enabled '*working'* environment, i.e. a STM, rather than an archive.

2.4.1 Drawing from Organisational, Corporate & Project Memories

Over the past twenty years there have been many concepts of '*shared memory*' relating to the use of technologies in the fields of information and knowledge management -

In ***information management***: *shared memories* (Konda et al., 1992); *team memories* for the management of information for business teams (Morrison, 1993); a *group memory* as a large store of information that can be searched, contributed to and modified (Wharton & Jefferies, 1993); *group memories* to store and share information based on appropriate information management strategies for groups rather than individuals (Berlin et al., 1993); *corporate memories* for information management (Megill, 1997); *common information spaces* (Bannon & Bodker, 1997); *shared information spaces* for collaborative design (Davis et al., 2001); and more recently a *group memory* tool (*Hipikat*[4]) formed from the information stored in a project's archives (Cubranic & Murphy, 2003).

In ***knowledge management***: the use of *organisational memory* to retain the intellectual capacity of knowledge workers with industrial application tools, such as - *QuestMap* and *Compendium*[5] (Conklin, 1992; Conklin, 2001); *organisational memory* in relation to cooperative awareness (Rammage & Reiff, 1996); *organisational memories* as important in learning processes (Huber, 1996); *organisational memories* to co-ordinate distributed knowledge (Perry et al., 1999); *CoMem*[6], *a corporate memory* as a repository of knowledge in context for design re-use (Fruchter & Demian, 2002; Demian & Fruchter, 2004); the benefits of a *project memory* to engineering design (Mekhilef et al., 2005); *project memories* for global design teams (Grierson et al., 2006); and, *project memories* to facilitate the design process (Monticolo et al., 2008).

Whilst the focus of this research is information management rather than knowledge management these areas often overlap, indeed as noted above they are sometimes referred to interchangeably.

There is an extensive investigation of OMs (also referred to as *corporate memories*) in the organisational theory literature (Walsh & Ungson, 1991), although its direct relationship to technology is more recent (Perry et al., 1999). The concept of PM, often regarded as a subset of OMs is not a new one. It has been around since the mid 1980s, with greatest interest in the 1990s. Lately research in this area has been limited. Definitions of these memories include –

> *"In its most basic sense, organizational memory refers to stored information from an organization's history that can be brought to bear on present decisions."* and *"…organizational memory is not centrally stored, but distributed across different retention facilities."*
>
> (Walsh & Ungson 1991, p.61; p.62)

> [OM] *"…is the attempt to capture a residue of the processes and rationale in an organisation,…"* (Ramage & Reiff, 1996, online)

[4] Hipikat – a tool that informs an implicit group memory for software developers.

[5] QuestMap and Compendium – tools that support the process (not just products) of the knowledge of a team's daily work, acting as an organisational memory. Compendium supersedes QuestMap and can be downloaded at http://cognexus.org/id66.htm.

[6] CoMem – a prototype corporate memory system which allows users to explore accumulated project memories.

> *"….the reuse system will be a corporate memory, a rich, detailed repository of knowledge in context."* (Demian & Fruchter, 2004, p.12)

> *"We propose that a 'project memory' is a subset of organisational memory that incorporates the memory of coalitions (ie project teams), as well as the memories of the individuals involved. It attempts to capture, retain and integrate 'hard' project data (such as database records, documents, and standard operating procedures) with 'soft' items (such as stories, recollections of critical events, and details about decisions processes."* (Weiser & Morrison, 1998, p.152)

> *"A project memory is simply an organizational memory for a project team* [p.4]*…an augmented memory that is based on information technology.* [p.3]*"* (Conklin, 2001, p.3,4)

These systems have often been ignored in industry in the past as a resource for a number of reasons. Western culture has come to value results above process; and many organisations collect too much information which is difficult to revisit and often fails to capture the emerging design knowledge, the history and the context behind the retained formal documents. There are also issues of the additional overhead needed to document processes; the tools are often complex and cumbersome and they can inhibit the natural flow of the design process (Grierson et al., 2006). The author's thinking on PMs draws on but also differs from the literature in the following ways -

1. Unlike Walsh and Ungson's (1991) comprehensive conceptual framework for OMs with its bias towards a storage model, the author argues that PMs need to be **active and 'living' repositories**. Not simply capturing history, but dynamic stores for management and educational purpose during project work (Grierson et al., 2006).
2. PMs require a **centralised** storage space unlike OMs and CMs which have information distributed across a number of different but networked retention facilities.
3. The author agrees with Conklin, Fruchter and Demian, that whilst organisations are adept at collecting information and artefacts, they are weak at retaining the **context** (or rationale) behind their generation (Conklin, 1992); and that PMs should be –

> *'…a repository of knowledge in context; in other words, it is an external knowledge repository containing the corporation's past projects that attempts to emulate the characteristics of an internal memory, i.e. rich, detailed and contextual.'*
>
> (Fruchter & Demian, 2002, p.94)

4. With the shift towards the globalisation of design and increasing collaborative design practice there is now a need to record more contextual and informal information and externalise the processes undertaken to support design decision making (Grierson et al., 2006).
5. Unlike a *Group Memory* broadly defined as a common repository of online, minimally structured information of persistent value to a group (Berlin, et al., 1993), a PM requires to be **organised** and **structured** for the quick locating of, and easy access to, information during project work.
6. And finally, like Huber, the author agrees that the PM is important to the **learning** process –

> *"... to demonstrate or use learning, that which has been learned must be stored in memory and then brought forth from memory; both the demonstrability and utility of learning depend on the effectiveness of the organisation's memory."* (Huber, 1991, p.106)

A PM should support student learning during distributed project work as well as affording learning opportunities from its stored content at a later date.

2.4.2 Project Memory Definition

Studies at the University of Twente into www-supported project work, highlighted the need for support in terms of workflow management; the storing and sharing of information and resources; recording of process and progress; and the failure of students to plan and reflect (Van der Veen & Collis, 1997). A PM is a potential mechanism to support all of the above. A PM is a shared workspace, an information space to allow the integration of information and knowledge to form new ideas and knowledge. Early work by the author identifies its purpose as -

- sharing project information and knowledge,
- managing workflow,
- supporting documentation,

- planning project progress,
- supporting student learning and reflection (Grierson et al., 2006).

In relation to Project Memories, the author's thinking draws from and develops on the work of Bannon and Kuutti (1996), Weiser and Morrison (1998), and Conklin (2001). PMs are best suited to distributed work, in particular asynchronous work, since there are fewer opportunities for direct communication and greater chances for misunderstanding (Grierson et al., 2006).

2.4.3 In Support of a Project Memory - Benefits to students

One of the recurring issues the students reported in the case studies was the time it took to store distributed project information. Unlike OMs which tend to be an add-on and often require extra effort (Conklin, 2001) PMs are an integral part of distributed project work. A rich and well organised PM affords a number of benefits to students to compensate for the time taken to populate the PM. These include –

1. Supporting distributed-design information storing by –

- the coordination of project resources;
- spending less time looking for information;
- helping to avoid duplication of information; and
- making information accessible 24/7.

2. Supporting distributed team work by –

- providing awareness of global sides (Carmel 1999);
- supporting decision making;
- supporting shared meaning;
- supporting collaboration;
- providing an archive that functions as a collective memory (Gross et al., 1997);
- providing a 'living memory' during project work that tells a 'story' (Conklin, 2001).

3. Supporting student learning by -

- Playing a role in supporting knowledge building and knowledge sharing within teams (Roschelle & Teasley, 1995; Dillenbourg, 1999) and enabling students to collaborate in the building of a shared representation of the design problem (Nicol et al., 2005).

- Constructing resource collections. The concept of knowledge structuring is important because the more opportunities students have to actively inter-relate concepts, ideas, facts and rules with each other and with prior knowledge, the deeper the understanding and learning (Jonassen & Carr, 2000; Denard, 2003).
- Preparing students for industry in a globalised market.
- Providing a rich archive from which,
  - lessons can be learnt;
  - re-usable learning objects can be harvested; and
  - opportunities for reflection can be afforded.

2.4.4 Criteria for a Project Memory for d-DIS

Whilst the content of each PM will be unique, determined by the context of the project, its goals, tasks, problems and the people and circumstances involved, five broad key criteria have been identified for a PM for d-DIS. These have been derived from the literature and from the findings of the case studies. These are listed and will be discussed below –

1. A PM is a Centralised Store
2. A PM contains both Formal and Informal Information
3. A PM presents a Comprehensive Record
4. A PM is Contributed to Frequently
5. A PM is Organised and Structured.

1. A Centralised Store

For more than a decade the literature has highlighted that distributed work requires a centrally stored common information space to store, share and manage information (Bannon & Bodker, 1997; Perry et al., 1999; Schmidt & Bannon, 2002; Fruchter & Demian, 2002). Thissen et al. (2007) note that an appropriate shared storage facility is very important for effective work, particularly in asynchronous project work; and,

> *"To support long-term asynchronous collaboration as in global design teams it is crucial to provide an archive or repository that functions as a group memory."* *(Gross et al., 1997, p.20)*

As noted previously, whereas OMs tend to be a web of distributed stores, PMs require one centralised store or a single interface, even though this may consist of a number of systems (Conklin, 2001).

In the Case Studies several teams reported from experience that using too many systems meant information was fragmented and duplicated. Students became frustrated and communication weakened as a result. A centralised store, accessible from any location at any time (24/7) is therefore the first of the criteria.

2. Contains both Formal and Informal Information

In the past the problem has not been so much the storing of formal information but a lack of storing of context and rationale to give meaning and understanding (Conklin, 1992). There is a need to explicitly express the requirements, the preferences and the reasoning for the final solution and to outline the evolution of a design and its processes, rather than simply storing the final outputs (de la Garza & Oralkan, 1995). Others (Bannon & Kuutti, 1996; Fruchter & Demian, 2002; Konda et al., 1992) reinforce this need to add context to distributed work.

Informal information and communications contain this necessary context. Sharing contextual information and other informal information, for example, *social information*, information about *actions & decisions*, *rationale*, *the organisation of the team* or *tasks*, amongst distributed workers is time consuming, unwieldy and not instinctive (Cramton, 2001). Cramton also point out that a lack of contextual information can result in misinterpretation of communication, misattribution concerning remote partners and the development of ethnocentrism within a team. (Cramton, 2001).

Research has highlighted the need for informal communication as a driver for successful teamwork (Johanson & Torlind, 2004; Kotlarsky & Oshri 2005; Hinds & Mortensen, 2005). In addition Cramton and Orvis (2003) note informal information and communications strengthens global teams. Their project studies show that social information can impact positively on the workflow and the productivity of distributed projects, because team members will know more about each other and work together more successfully.

Informal information also provides the *'richness'* required to compensate for the lack of f2f communication in distributed work. Research studies note *'richness'* takes its form in a variety of information carriers and modes of exchange. These include the form of text, sketches, drawings, video, pictures, gestures, and speech (Hales, 1987; Ullman, 1987; Leifer, 1991).

3. A Comprehensive record

A PM should be considered as a subset of all project information acquired or generated by the global team. However, it is difficult to determine the exact amount of information required to be stored in distributed project work due to the complexity of design work and the multiple factors influencing it. Whilst information overload should be avoided and information should be kept to a minimum throughout the process (Suh, 1990), in education, a comprehensive picture needs to be retained to support student learning both during and after distributed project work. '*Comprehensiveness*' includes both practice-related and product-related project information.

In terms of a PM and a comprehensive record, the case study students felt it was best to keep 'critical' or 'significant' documents. They defined 'critical' as something important to record, such as turning points, decisions; and 'significant' documents as the final deliverables, justification, minutes, actions and decisions. There is also the need as outlined above to store and share more informal information in distributed work to support and make meaning of the stored formal information.

4. Contributed to Frequently

In his studies on global software teams Carmel notes the need for distributed workers to contribute information frequently to a shared information space in order to maintain a complete picture of what is happening at the remote site(s) (Carmel, 1999). Students in the case studies found that at a lack of regular contribution to their shared information spaces gave an impression of lack of engagement which in turn caused a reduction in overall team motivation. Frequent contribution of project information to a shared information space at the point of acquisition or generation, helps support remote site awareness and reduces gaps in a PM.

5. Organised and Structured

The final criterion supports the easy access to and retrieval of information, a PM should be well organised and structured. This has been highlighted in the literature. The early work of Wharton and Jeffries outlines the role structuring plays in the context of group memories (Wharton & Jeffries, 1993). The importance of structuring project information has been made, in industrial studies (Davis et al., 2001) and in an educational context (Grierson et al., 2004).

Research suggests that constructing and organising resource collections contributes to learning by requiring students to analyse, organise and reflect on their knowledge (Jonassen & Carr, 2000; Denard, 2003). Other research also supports this; with students reporting that the creation, structuring and sharing of task relevant documents supports design and project learning (Nicol & MacLeod, 2004). Bondarenko and Janssen's (2005) study suggests that for the most meaningful information structures, support should be given to regrouping and re-structuring shared information as the task goes on.

2.5 Educational Context

The literature review will now conclude by placing the work within its educational context. Three key educational constructs relevant to the thesis will be introduced; the global designer, project-based learning and reflection.

2.5.1 Educating the Global Designer

With a shift to the globalisation of business markets and services and the geographic distribution of working teams, it is essential that engineering graduates are prepared for professional careers in a global context (Herder & Sjoer, 2003; Bohemia & Roozenburg, 2004; Ion et al., 2004; Sheppard et al., 2004; see also Bohemia et al., 2009, for a full and comprehensive review). In preparing engineering students to work in this environment, often more skills are required compared to those used when practising traditionally (Hoegl et al., 2007).

Over the last decade educators have been developing educational programmes and affording engineering design students the experience of working in cross-disciplinary, cross-institutional, cross-cultural and geographically distributed contexts. For example, the Project Oriented Learning Environment (POLE) Project where students from different countries developed process-oriented expert knowledge through interdisciplinary teamwork using modern information and communication technologies (Elspass & Holliger, 2004); the European Global Product Realisation (E-GPR), an international course that helped students become competent members of product development teams (Zavbi & Tavcar, 2005); and the Global Studio which integrates elements from a design studio model of education with elements that equip students to work in distributed teams (Bohemia & Harman, 2008).

Global design project experience has been shown to provide a rich cultural experience, in addition to the opportunity to employ design management strategies and use technological support tools which are increasingly relevant in these global design environments (Wodehouse et al., 2007). The author was involved in the development of one such initiative – the Global Design Class, through the JISC/NSF funded DIDET Project[7] (Digital Libraries for **D**istributed **I**nnovation in **D**esign **E**ducation and **T**eamwork). The central goal of the DIDET Project was to enhance student learning opportunities by enabling students to take part in global, team-based design engineering projects, in which they directly experienced different cultural contexts and stored and accessed a variety of digital information sources via a range of appropriate technologies. The DIDET Project achieved its goal of embedding major change to the teaching of Design Engineering in the University of Strathclyde's Global Design Class and the class has been both successful and popular with students since it first ran in 2006. Each of the three institutions involved in the DIDET project developed its own independent class –

- University of Strathclyde, Glasgow, UK – 56521 *Global Design Class* – an optional class for 5th year Undergraduate Product Design Engineering students and Postgraduate Global Innovation Management students;
- Stanford University, CA, USA – ME397 *Design Theory and Methodology* **-** *Distributed Design with Digital Libraries* **-** an existing class for students at Stanford's Center for Design Research; and

[7] www.didet.ac.uk

- Franklin W. Olin College of Engineering, MA, USA – 2260 *Distributed Engineering Design* - an optional class for undergraduate students.

Common to the three classes was - the Global Design Project, developed by staff collaboratively at Strathclyde, Stanford and Olin over a period of eight months. See Appendix 2.1 for Project Briefs. Distributed teams of students worked together on a short design project experiencing the realities of global design. The Global Design Project provided the vehicle for the thesis studies from which the set of Principles for distributed design information storing (d-DIS) developed. Many researchers agree that distributed teams need guidance and managerial support beyond the simple provision of an electronic groupware system (Lipnack & Stamps, 1997; Jarvenpaa & Leidner, 1999; Sheppard et al., 2004). The Principles are intended to further support the education of the global designer.

2.5.2 Project-based Learning

The Global Design Project is grounded in Project-based Learning (sometimes referred to as 'PjBL' to avoid confusion with 'Problem-based Learning (PBL)). PjBL is an instructional strategy used to engage students in 'real world', often multi-disciplinary and technology driven tasks, to bring about deep learning. It takes a student-centred collaborative approach and includes the role of a facilitator (Thomas, 2000). It is very similar to PBL but also differs in several ways. PjBL will typically begin with an end product which students are required to research, plan and design. PBL, on the other hand, uses an inquiry model, where students are presented with a problem and are required to gather information and new knowledge, without the necessity of an end product. Further differences between PjBL and PBL at tertiary level can be found (Perrenet et al., 2000) -

- PjBL is more directed to the *application* of knowledge, whereas PBL is more directed to the *acquisition* of knowledge.
- PjBL is usually accompanied by subject courses whereas PBL is not.
- Management of time and resources by the students as well as task and role differentiation is very important in PjBL.
- Self-direction is stronger in project work, compared with PBL, since the learning process is less directed by the problem.

PjBL has many benefits when compared with traditional teaching methods. It affords deeper knowledge of subject matter, increased self-direction and motivation, and improved research and problem-solving skills (Curtis, 2001).

2.5.3 Reflection

Reflection has recognised value, both in education and in industrial practice. In terms of student learning, it can identify conflicts and possibly resolve them. It can also highlight new relationships between stored information, developing inferences (Eastman, 2001). Reflection is crucial to engineering designers' practice. The work of Schon (1983) has been widely recognised in design research (Valkenburg & Dorst, 1998) as he identifies the importance of reflection for those working in professional practice. Other research work such as Kolb's Learning Cycle (Kolb, 1984) and Cowan's Reflective Model of Reflection – (*reflection-for-action, reflection-in-action* and *reflection-on-action)* (Cowan, 1998) have shown that learning can be enhanced when it is organised around cycles of reflection. Oliver (2001) identifies three key issues. Students evince weaknesses in their initial planning and in workflow management (*reflection-for-action*). They place too much emphasis on finding information and resources rather than critically evaluating and interpreting these resources in terms of the problem under investigation (*reflection-in-action*). Oliver also identified that students are not good at reflecting back, leading to poor evaluation of progress towards the problem solution (*reflection-on-action*). He does suggest though that online technologies can improve students' critical thinking skills when solving complex problems (Oliver, 2001). Designing reflection into class or project activities helps to highlight the importance of reflection and also encourages students to engage in this process.

2.6 Summary and Thesis Focus

The review of the literature has identified a number of issues associated directly with distributed design information storing, such as poor information access and acquisition; managing engineering design information takes time; difficulties exist due to the use of technologies; information collections are often unorganised and lack structure; stored information lacks context and lost or incomplete information results in a partial 'picture' or 'story' of the project development. These all contribute to students requiring guidance on distributed design information storing.

Engineering design is an information intensive activity and the literature has shown that a significant amount of time is spent managing design information rather than on the design task itself (Court, 1995; Marsh, 1997). Yet the literature has established that still little is known about the use of information and documents by engineers (McMahon et al., 2004).

This work seeks to address the lack of guidance on engineering design information and the issues associated with students not being able to manage distributed information adequately. See Figure 2.9 for the **Thesis Focus**.

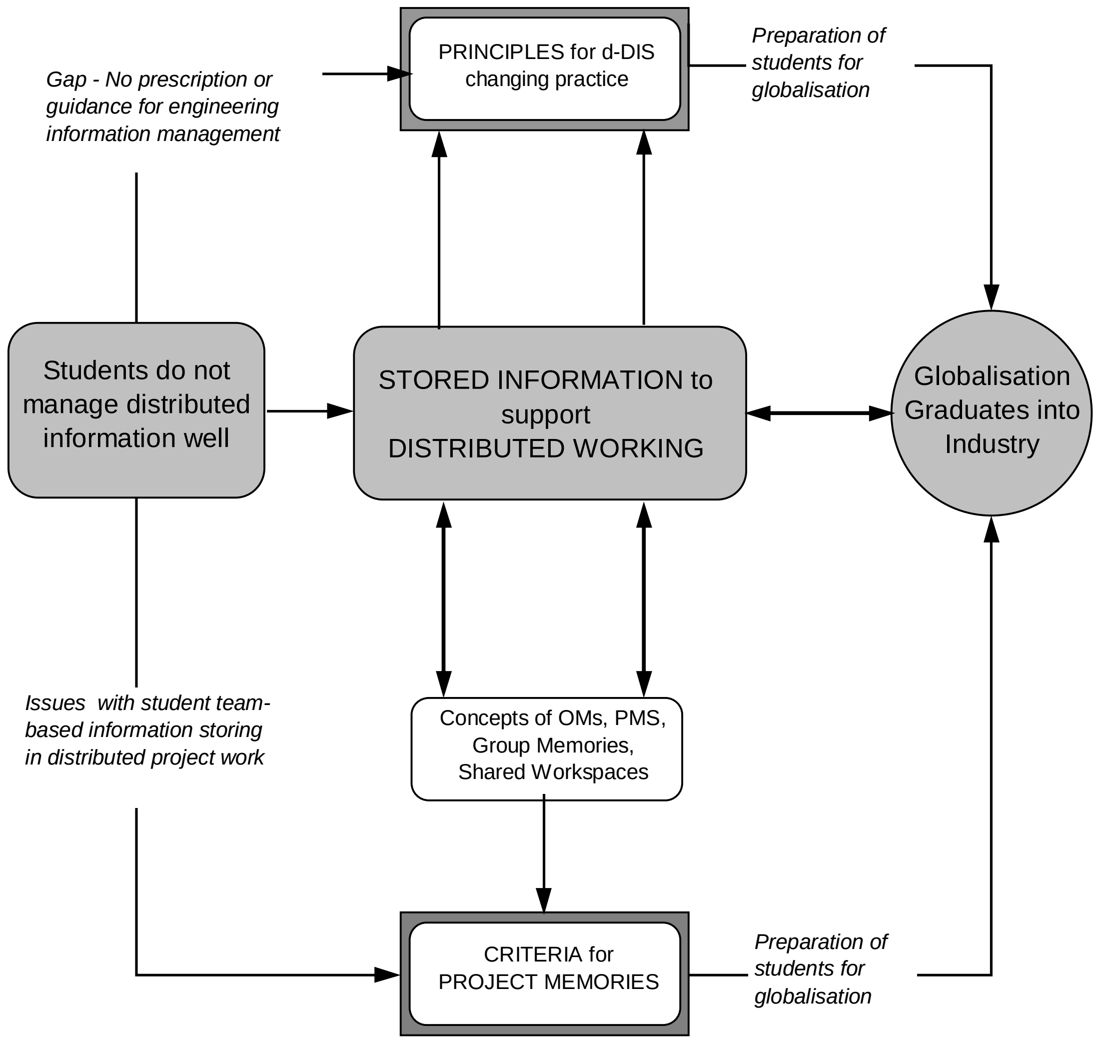


Figure 2.9: Thesis Focus

Following the review of the literature, the thesis will now focus on and set out to -

- *understand better how students in a distributed design team-based context store design information and knowledge*;

so that,

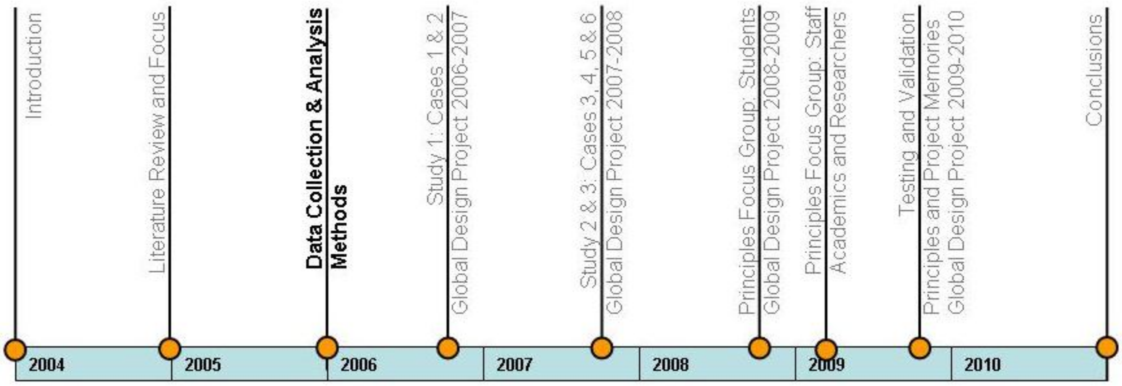
- *support for enhancing the distributed design information storing experience can be developed*;

in order to,

- *better prepare students for their role of graduate engineer in an ever increasingly globalised world.*

The research methods used in the thesis and their theoretical basis will now be covered in Chapter 3.

3 Data Collection and Analysis Methods



3.1 Introduction

This Chapter focuses on the data collection and analysis methods used to examine the student team-based studies in the second stage of the work – *Description I*. It begins by outlining the theoretical basis for each method in Section 3.2. Methods specific to this research are covered in greater depth in Sections 3.3 and 3.4. These methods are also used to validate the prescriptive element of the work as presented in Chapter 7.

3.2 Theoretical Basis for Research Methods

The main research methods adopted in the thesis (and the sources used for guidance) are –

- the **Case Study Method** (Yin, 2003);
- **Content Analysis** (Krippendorff, 2004; Weber, 1990);
- **Questionnaires** and **Semi-structured Interviews** (Oppenheim, 1992); and
- **Focus Groups** (Bryman, 2004).

Engineering design studies tend to utilise a range of methods or adopt a mixed method approach due to the requirement for depth of understanding. The theoretical basis for each method used will now be outlined, before describing the implementation of the methods in the work of the thesis.

3.2.1 Case Study Method

Case studies have been used in this work as they are a distinctive form of empirical inquiry, focusing on the desire to understand phenomenon within a 'real life' context at a close level of detail. This was important to this work. Case studies suit the needs of the sole researcher and in this case give the author the opportunity to focus on a few examples in a specific contexts (Blaxter et al., 1996). The goal in this thesis is to expand and generalise theories (analytical generalisation) and not to enumerate frequencies (statistical generalisation). Yin's Case Study Method (Yin, 2003) has been used as a basic framework to present the findings on the first of the research questions - *'How do students store and share design information and knowledge in distributed team-based project work?'*

Yin outlines three types of case study – exploratory, explanatory and descriptive. Descriptive case studies have been selected as they are complementary to *Blessing et al.'s Descriptive/Prescriptive DRM*, used in this work. These descriptive case studies explore the information storing practices of student distributed teams in order to increase understanding and to identify key impacting issues for future change. Case studies within educational institutions, are typically of the descriptive type of case study.

One of the primary traditional prejudices against case studies is a lack of rigour and reliability. To overcome this and to ensure rigour and consistency, Yin's Case Study Research Design was adopted including the use of a Case Study Protocol and a Case Study Process (Yin, 2003). This was developed at the outset of the studies and is regarded as essential when carrying out multiple-case studies. Yin also recommends four 'tests' for validity –

1. Construct validity – ensuring the correct relationships are being studied,
2. Internal validity – establishing a casual relationship,
3. External validity – establishing the domain to which the study's findings can be generalised,
4. Reliability - demonstrating that the operations of the study can be repeated.

Case studies are best developed from a convergence of information from different sources. This mix of methods gives greater insight, and enhances and strengthens findings from other sources. Case studies allow for a mix of quantitative and qualitative evidence to address the research questions.

It was also important to garner evidence from multiple case studies as this is considered more compelling and robust (Heriott & Firestone, 1983); deepens understanding and can increase generalisation (Yin, 2003). With two or more cases the possibility of direct replication or reinforcing repeatable outcomes is afforded.

3.2.2 Content Analysis

Content Analysis was chosen for the study of the information in the student project sites due to its unobtrusive nature; its ability to provide a systematic method of analysing qualitative data and the need for rigour.

> *"Content Analysis is an approach to the analysis of documents and texts that seek to quantify content in terms of predetermined categories and in a systematic and replicable manner."* (Bryman, 2004, p.181)

With its tradition of coding, unitising and clustering, content analysis has long been a method of analysing data, quantitative and qualitative, in a rigorous manner (Krippendorff, 2004; Weber, 1990). Its methods have been used in this thesis to systematically quantify the content of the project information stored by students in their online project sites or shared workspaces, across a number of cases, and to analyse particular phenomenon, behaviour and issues from the more qualitative sources like questionnaires, interviews and focus groups. A Glossary has also been included in this work for clarity of meaning. In order to ensure objectivity and,

> *"…to make valid inferences from the text, it is important that the classification procedure be reliable in the sense of being consistent: different people should code the same text in the same way."* (Weber, 1990, p.12)

Krippendorff (2004) advocates a series of steps to add rigour which have been followed in this work –

- Unitising – identifying independent elements or units;
- Sampling – reliance on sampling plans;
- Recording/coding – reliance on coding instructions;

- Reducing data to manageable representations – relying on methods for categorising, summarising or simplifying the data;
- Inferring contextual phenomenon – reliance on analytical constructs or models, recognising patterns.

In this research, the content in the student online project sites and the questionnaires, was examined, quantified, tabulated and visualised using spreadsheets, bar charts and timelines. Findings from the content analysis of the initial descriptive studies were then reduced using coding and clustering for systematic rigour.

3.2.3 Questionnaires and Interviews

Guidance on questionnaire design was taken, e.g. the design and planning of questionnaires; type of questions, scales to be used, etc. (Oppenheim, 1992). Closed questions with matrix-tabled scaled responses were used in this work, in the questionnaire design, alongside more open questions for greater insight.

Interviews were conducted in this work to uncover information of the students' personal experiences. They were used firstly to validate the findings of the analysis of the online sites and the results of the questionnaires; and then to engage in dialogue with team members on emergent issues. Small group interviewing afforded access to detailed information and depth quickly. They also tend to be more informal putting participants at ease and giving them a level of control during the process (Oppenheim, 1992). Semi-structured interviewing was chosen as it allowed control of the sessions to an extent through a short set of pre-prepared questions focused around the findings of the analysis of the student team project sites; flexibility in questioning; and the author could also probe for additional information where necessary (Frankfort-Nachmias & Nachmias, 1996). Results and findings were fed back to participants and this acted as a source of phenomenological validity in itself (Bronfenbrenner, 1976).

3.2.4 Focus Groups

Focus groups were used in this work with the purpose of developing and validating the Principles, following completion of the case studies. Use of the Focus Group method in this research work will be presented as integral to the development and validation of the Principles, in Chapter 6. A Focus Group is a form of qualitative research in which a group of people are asked about their opinions and attitudes towards something, for example, a product, a service, or an idea. They differ from group interviews in that they place emphasis on the interaction within the group, around the inquiry set by the researcher, rather than the participants simply responding to researcher's questions (Morgan, 1998).

3.2.5 Mixed Methods

The implementation of a single research method is rejected in this thesis in favour of a mix of methods to provide a richer more insightful understanding of the phenomenon and processes being studied and to corroborate findings. Most engineering design studies use a mix of methods.

3.3 The Methods as used in the Studies

Having identified the theoretical basis for using particular research methods, this section now outlines these main methods as used in the research. Six global teams were used as case studies. Table 3.1 provides an overview of the studies undertaken.

	Case	Dates	Partners	Students	Mode of Working
Study 1	**Case 1**	October 2006-2007	Stanford University, Stanford, U.S.A.	UK-side = 3 USA-side = 2	**Asynchronous** over 3 weeks - 8 hours (GMT)
	Case 2			UK-side = 3 USA-side = 3	
Study 2	**Case 3**	October 2007-2008	Swinburne University, Melbourne, Australia	Strath-side = 2 Swin-side = 3	**Asynchronous** tasks (follow-the-sun) over 2 weeks + 9 hours (GMT)
	Case 4			Strath-side = 3 Swin-side = 3	
Study 3	**Case 5**	November 2007-2008	University of Malta, Msida, Malta	Strath-side = 2 Malta-side = 3	**Synchronous** – tasks with VC over 2 weeks + 1 hour (GMT)
	Case 6			Strath-side = 2 Malta-side = 3	

Table 3.1: Overview of Descriptive Case Studies Parameters

3.3.1 The Case Study Method

The Case Study Method is used as an overall strategy to seek to understand student information storing practices in a distributed design context. The analysis of the data is presented as six case studies. The findings from these cases form the foundation for the research, and support the development of a set of guiding Principles for d-DIS and the development of the Project Memory Concept and Model. Whilst all studies are set in the context of a Global Design Project within one of the University of Strathclyde's classes – the Global Design Class, each case will have slightly different parameters; for example different partner nationalities, modes of working, numbers of students.

The complete set of data sources for the six case studies is presented in Table 3.2.

Data Source		Quantitative	Qualitative		
		Analysis of archived online project work – Content Analysis	**Questionnaires** (from)	**Interviews (UK)**	**Student reflection/ reports (UK)**
Study 1	**Case 1**	Content stored in *LauLima* and emails	1 UK-side 1 USA student (via interview)	2 students	reflective contributions 3 reports
Study 1	**Case 2**	Content stored in *LauLima/ Socialtext* and emails	1 UK-side 1 USA-side	2 students	reflective contributions 3 reports
Study 2	**Case 3**	Content stored in *Socialtext* and emails	1 Strathclyde-side 1 Swinburne-side	2 students	reflective contributions 2 reports
Study 2	**Case 4**	Content stored in *Google Docs* and emails	1 Strathclyde-side 1 Swinburne-side	2 students	reflective contributions 2 reports
Study 3	**Case 5**	Content stored in *Wetpaint* and emails	1 Strathclyde-side 1 Malta-side	2 students (as in Case 3)	reflective contributions 2 reports
Study 3	**Case 6**	Content stored in *Google Groups* and emails	1 Strathclyde-side 1 Malta-side	2 students (as in Case 4)	reflective contributions 2 reports

Table 3.2: Data Sources for the 6 Case Studies

The Case Study Research Questions

The case studies address the first of the research questions –

How do students store and share design information in distributed team-based project work? –

- *What information content is stored?*
- *Where is information stored?*
- *When is it stored?*
- *How is it stored and why?*

The *'what', 'where'* and *'when'* questions are answered by examination of the information students stored in their online project sites; analysed quantitatively. *'How'* and *'why'* questions are more adequately answered through qualitative methods and techniques such as questionnaires and interviews. These methods add the richness and depth required of the study. UK students, as part of their class assessment, were required to undertake reflection in class and reflective report writing. This contributed further evidence to the case studies. Student agreement at the semi-structured interviews validated the findings of the analysis of the stored content. Table 3.3 summarises the data sources used to respond to case study research questions.

Research Questions	Sources of Data for Descriptive Case Studies
How do students store and share design information in distributed team-based project work?	Analysis of stored project work; questionnaires; interviews and student reflection
What do they store?	Analysis of stored project work; questionnaires; interviews and student reflection
Where do they store it?	Analysis of stored project work; questionnaires; interviews and student reflection
When do they store it?	Analysis of stored project work; questionnaires; interviews and student reflection
Why do they store it?	Questionnaires; interviews and student reflection.
What do they value?	Questionnaires; interviews

Table 3.3: Data sources addressing the Case Study Research Questions

Sampling

Distributed design education is fairly labour intensive typically with high staff to student ratios, resulting in small numbers of students in global design classes. This ensures a good distributed experience. Consequently, should any students or teams withdraw from a study, this makes the sample size smaller still, as was the case with one institution withdrawing in Study 1. There is no clear consensus on what is an acceptable sample size (Ahmed & Wallace, 2002). A small sample size makes generalisation difficult, however good practice guidelines are still achievable (Miles & Huberman, 1994). Sampling determination for each case is outlined in more detail in Chapter 4 in the reporting of the case study findings.

Consent

Many ethical issues apply to engineering design research in particular those relating to participants and to documentation from industry, such as informing, sensitivity, recording, anonymity and confidentiality (Frankfort-Nachmias & Nachmias, 1996). Permission and consent was sought from all students involved in the Global Design Projects to access, examine and re-use stored project work for educational, research and other non-commercial purposes. See Appendix 3.1. In addition permission was sought to carry out interviews under the University of Strathclyde's 'Ethics Code of Practice' governing the implementation and conduct of investigations on human beings. Approval was granted for carrying out interviews by the Departmental Ethics Committee. The interviews were deemed 'routine' and 'non-invasive' and as such did not require full University Committee Approval. See Appendix 3.2 for Ethics Approval Documentation, including Information Sheet and Consent Form for participation in Semi-structured Interviews and Focus Groups.

3.3.1.1 Case Study Design

The Case Study Research Design was developed according to Yin's three stages (Yin, 2003) –

1. *Define and design the case study adopting appropriate research methods.* To ensure rigour, consistency and reliability across the cases a set of prescribed procedures were followed - the **Case Study Protocol**, see Appendix 3.3. This included an overview of the case study; research questions; units of analysis; criteria for interpreting the findings and reporting formats. In addition a **case study process** was followed, see below Section 3.4.1.2.

2. *Prepare, collect and analyse data for each case.* Yin's three principles of data collection were adopted -
   (i) Use **multiple sources of evidence** - data/documents, questionnaires, interviews used and examination of student reflection.
   (ii) Create a **Case Study Database** - paper-based and electronic versions kept.
   (iii) Maintain a chain of evidence - **Case Study Records** of raw data of findings using coding and clustering produced; development of work from empirical studies (see Appendices 3.4 for coding and 3.5 for Case Study Record).
3. *Analyse data and conclude across cases* - see Chapter 5.

Although the context of the multiple case studies slightly differed, cases still produced literal replication (similar results) across themes. This will be discussed in more detail in Chapter 5.

Yin recommends four 'tests' to ensure rigour in case study design. The case study tactics used and their application in this work are summarised in Table 3.4.

Tests	**Case Study Tactic**	**Application in this research**
Construct Validity	Use of multiple sources of evidence.	Content analysis of stored information in online project sites; use of questionnaires and semi-structured interviews; review of student reflection.
	Have key participants review draft findings.	'Picture' of information stored verified by semi-structured interviews.
Internal Validity	Explanation building.	Discussion of the emerging case study findings and issues; triangulation of data sources.
External Validity	Expert Focus Groups Selection of representative participants	Presentation of Principles to student groups. Presentation of Principles to selected researchers and academics, expert in related fields.
Reliability	Use of Case Study Protocol	Case study protocol to guide data collection and case study presentation.
	Develop Case Study Records and database.	Keep record of all coded raw data. All data/documentation stored in hard copy and electronic form for each case.

Table 3.4: Compliance with Yin's Four Tests for Validity in the Work of this Thesis

3.3.1.2 Overview of Case Study Process

The quantitative data from the student online project sites, and the qualitative data collected from the questionnaires and from student reflective reporting, of each participating team, were compiled to generate a 'picture' of each case's distributed information storing behaviour. The findings, for each case, were visualised using bar charts, timelines and graphics, and shown to the UK-side of each global team in a semi-structured interview, in order to validate the findings of the analysis; clarify any errors or omissions and elaborate where necessary, thus increasing accuracy.

The findings and results, from each case study, were coded (in order to be able to keep track of the data) and clustered (into categories). These categories related directly to the research questions – '*what*' information, '*where*', '*when*', '*how*' and '*value*'; and resulted in a series of Case Study Records of all findings and issues, one for each global team studied (Appendix 3.5). These were also summarised in reports for each Study. Visualisation using Mindmaps was used to draw out the key recurring issues and themes and to visualise the findings. These aspects of the work will be further detailed under the section on Content Analysis below.

The convergence of evidence from the cases laid the foundation for the research and helped form a series of recommendations which went on to support the development of a set of guiding Principles and the development of the Project Memory Concept to support distributed design information storing. Figure 3.1 overleaf provides an overview of the Case Study Process, towards this series of Recommendations.

Impact of Studies

It was crucial that the research had a low impact on the participating students and that it did not affect or compromise the student behaviour being investigated or the academic integrity of the class, during the project period. Key issues considered were -

- Researcher's impartiality - unobtrusive data collection methods and minimal intervention were employed; devoid of influence. No preferential treatment was given for those taking part. Clear boundaries were recognised by the author for roles played – as class tutor and researcher.
- Identity of case studies – students were unaware of which cases were being used in the study. All teams in classes were treated equally and as such no control groups were used.
- Student's awareness of the study – once selected, participants were made clear of why the study was being carried out; what was being studied; how information was being collected and what was to be done with the information.

- Class assessment – the study should not affect assessment. Student involvement was limited and restricted in terms of time, class constraints and timetabling due to other workload.

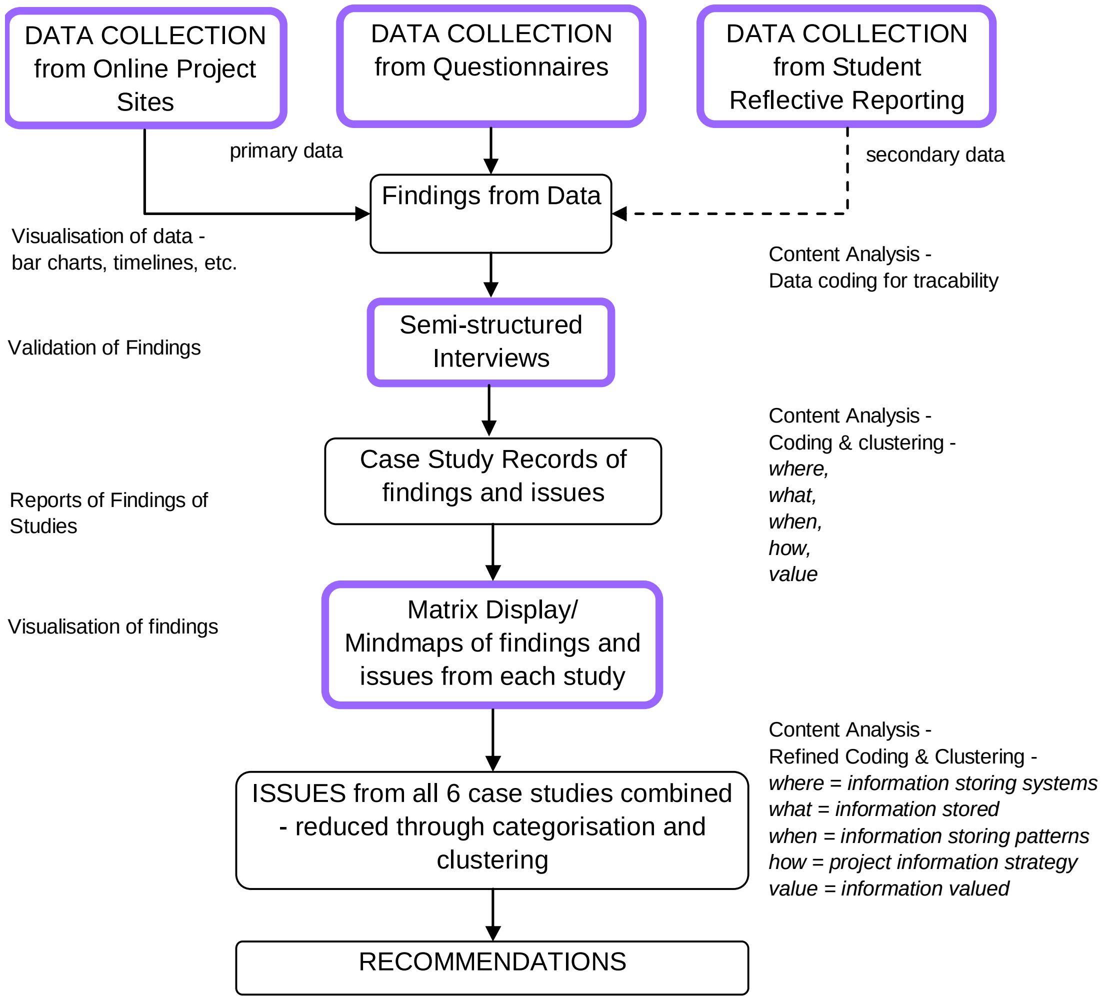


Figure 3.1: Case Study Process highlighting Research Methods Used

The requirement to maintain a low impact level on the classes being studied had in part an influence on the choice and design of data collection and analysis methods –

- *Data analysis of online student team project sites* – the information students stored could be indirectly and discreetly observed online, at any time, as they worked during the project and after the project without the need to involve students. All staff had access to student online project sites/shared workspaces for the purposes of monitoring and supporting classes.

- *Questionnaires* – were designed as part of UK student class reflection affording teams the opportunity to benefit and learn through reflection on their information storing practices on the Global Design Project. Global partners were emailed the questionnaire.
- *Interviews* – following analysis of online project sites and questionnaires, interviews with UK-sides added '*how*' and '*why*' information; and validated findings.
- *Analysis of class reflection and reflective reports* - examination of participating (UK) student reflection in class and reflective reports (secondary source material) afforded further deeper insights into how the teams stored distributed information, giving rationale and adding to each case study.

3.3.2 Analysis of Stored Information Content

The global student teams centrally stored and communally shared project work in online project sites. This will also be referred to as a Project memory (PM). Here project information could be accessed by team members independent of location or time; supporting decision making and project work. Essentially these online project sites operated as a '*short term memory*' (STM) for the team during the project and will form a '*long term memory*' (LTM) or archive beyond the life of the project. The content of the information stored by the teams was gathered and analysed to determine - *How students store and share design information in distributed team-based project work?*

3.3.2.1 Content Analysis Design

Content analysis of the stored information helped build the initial picture of the cases. Whilst valuable in terms of determining stored content, it should be noted that this method has drawbacks. It can be very time consuming; impractical to use across large numbers of cases; and is often non-transferrable, due to the uniqueness of case conditions.

Boundaries to study of content

The case studies examined the information content in team online project sites. Information content included both information acquired from external sources or generated by the team. Although emails were not centrally stored and as such should not form part of the PM, emails were included to establish the nature of their information content and determine what might be lost if they were not stored. Examination was restricted to shared information and did not include personal collections stored offline, i.e. paper sketches and files on PCs or laptops. Most of this information was photographed or scanned and uploaded; or transferred to the team's PM. Video conferencing (VC) sessions were not retained but key points from minuted VC sessions were examined. Information in external websites has not been included in the study due to the ephemeral nature of web links and sites. This included any videos uploaded and linked from *YouTube*[8]. Only video files stored directly in PMs were examined. Duplicated content was not quantified, for example, the information content in a pdf of the same Word Doc or information in a file which was also embedded on a web page. Table 3.5 indicates the study boundaries.

Included in information content analysis	**Not included in information content analysis**
Team centrally stored and communally shared workspaces or repositories	Paper project sketches (as these were unsuitable for sharing distributedly)
Emails	Email attachments (as these were also uploaded to online project sites)
Video stored directly into *Project Memories*	Files on PCs or laptops (as these remained with individuals; copies were uploaded to shared online project sites)
Chat stored directly into *Project Memories*	*YouTube* videos or links to other sites (as these were either removed or had potential to expire)
Summaries of minuted VC sessions	Duplicated content (affects quantification)
	Video conferencing (not retained by students)

Table 3.5: Stored Distributed Information Boundaries to Study

Information Definitions used

Early on in the studies it was apparent that to add rigour and consistency and to avoid misunderstanding and interpretation of meaning, that the definitions and terms used within the context of the studies had to be made explicit, see Figure 3.2 for key information terms used. A Glossary of 'information' terms was developed for use whenever questioning or interviewing; see Appendix 3.6.

[8] YouTube is a video sharing website - www.youtube.com

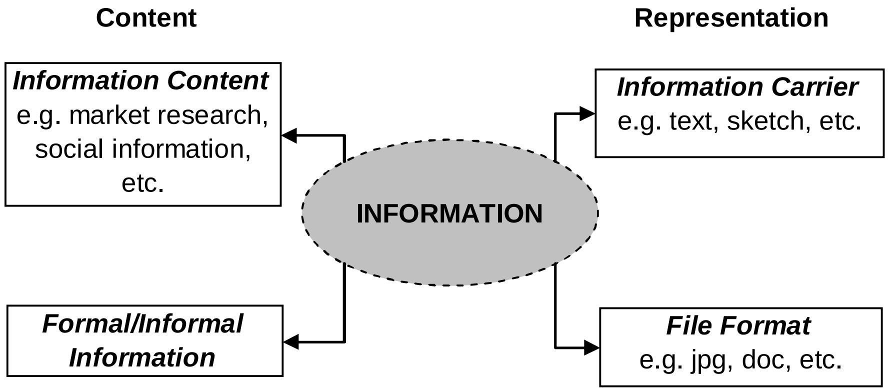


Figure 3.2: Information Terms Used in the Thesis

Coding/Classification

Codes are tags or labels for assigning units of meaning to information compiled in studies (Miles & Huberman, 1994). Coding was used in the studies to –

1. Maintain a chain of evidence and keep track of the data from the range of sources, see Appendix 3.4.
2. Organise, analyse and cluster emerging case studies issues.
3. Classify Formal and Informal information content in the online project sites and emails, see Table 3.6 and discussion below.
4. Analysis of content of Principles validation responses.

Information Content - Classification Scheme

Developing a coding scheme for the information stored in the online project sites proved difficult due to a lack of consistency of schema across other studies in engineering information management; the wide range of different terminologies used; and the differing views on classification. A decision was taken to examine the content within files and on web pages rather than simply count numbers of files, web pages and images, for two reasons. Firstly this gave greater granularity to the results and secondly there was also a need to establish whether students were storing more informal and practice-related information and to what extent.

There has been a shift in engineering education from a product-output focus to a practice-related focus with the need to record more informal information to support decision making (Grierson et al., 2006). Others have taken this approach (McAlpine et al., 2009). For the purposes of the thesis it was important to identify information content categories based on the product outputs and information generally acquired and produced by the student teams at various stages of design – the more Formal elements; and also the more Informal information, generated during the production of the results and the outputs. An information content classification/coding scheme, tailored to the context of the Global Design Projects (from design stages - market research to prototyping) was used to examine information content in the online project sites and emails -

1. ***Formal information content*** – information which can be identified as more product-related. It is more factual and declarative and is about the outputs and results derived from the stages of recognised design methods and processes, in particular Pugh's model of Total Design (Pugh, 1991); and also the systematic approaches of Pahl & Beitz (Pahl & Beitz, 1996) and Ulrich and Eppinger's integrative methods for product design and development (Ulrich & Eppinger, 2004). This type of information content includes *market research, user requirements, formal presentation of concepts, calculations, materials, assembly, detail design, testing, evaluation, manufacturing* and the *final solution*.
2. ***Informal information content*** **–** information which can be identified as more practice-related, produced as a result of generating the outputs whilst undertaking distributed project work. These terms were derived from a review of Organisational Memories (Perry et al., 1999; Conklin, 2001), Corporate Memories (Demian & Fruchter, 2004) and Project Memories (Weiser & Morrison, 1998; Bannon & Kuutti, 1996) and include *actions & decisions, design rationale, problems, social information, communications information, procedural information* and *organisational information on the team* and *tasks.* For complete list see Table 3.6. Two categories particular to distributed design information storing are *contextual information* and *locational information.*

Table 3.6 indicates the classification of the different Formal and Informal information content types. Completeness of the coding cannot be claimed. Nor is the list exhaustive. However, several iterations of coding in the development of the cases has shown selection of categories to be consistent, in the context of the Global Design Project. Following Study 1, only one new information content category arose from analysis of the sites, questionnaires and interviews - *locational information*. One code also decayed - *project scope*. Some codes merged - *user surveys/observation* and *product user requirements* became *product/user requirements* and *concepts testing* and *concept evaluation* became *concepts testing/evaluation.* See Glossary of information terms, Appendix 3.6 for definitions.

Formal Information: product-related	**Informal Information:** practice-related
Market Research	*Prior experience/knowledge*
Product/User requirements	*Design rationale*
Concepts	*Actions & decisions*
Concepts Testing/Evaluation	*Problems/issues/questions*
Calculations	*Discussions*
Detail Design/Prototypes	*Communications Information*
Detail Design/Prototypes Testing	*Social Information*
Functional Information	*Contextual Information*
Materials Information	*Procedural Information*
Components & Assembly Information	*Organisational information on tasks*
Manufacturing Information	*Organisational information on team*
Final results/solution	*Locational Information*

Table 3.6: Information Content Categories used in Global Design Project Studies

Units of Analysis

Instances of Formal or Informal information content were identified in the student online project sites, based on the above classification scheme. At the macro level the unit of analysis was a web page, or a text file, image file, video file or email message. At the micro level, the unit of analysis was a phrase or sentence within text or annotations on sketches. Occasionally an instance would be at a word level. For example, an instance of *'material information'* would result from an annotation of *'cardboard'* on a sketch of a coffee cup holder. Whilst viewing the online project sites and the information stored there, instances of either Formal or Informal information content were recorded in the margin of paper copies of the web pages or files. Individual *photographs of people/objects/models* were the unit of analysis for visual material. For example, an image of a coffee cup holder concept could return instances of *'concepts'*, *'materials'* and *'assembly information';* an image of a team member demonstrating a concept model could return instances of *'concepts'*, *'functional information'*, *'materials'* and *'assembly information'* and *'contextual information'*. See Appendix 3.7 for some marked up examples.

Information Representation – Information Carriers and File Formats

Engineering designers engage with a rich variety of media and modes of exchange of information (Hales, 1989; Leifer, 1991; Subrahmanian, 1992; Ion et al., 2004). This work uses the term *information carriers*. Table 3.7 lists the different information carriers used by the students when carrying out distributed design.

Text:	on web pages, in text documents, meeting minutes, reports, annotations
Sketches:	photographed or scanned
Engineering drawings:	photographed or scanned
Photographs:	of physical models/objects/people
Gantt chart:	spreadsheet of availability/ Mindmaps of research
Presentations:	PPT, text and images
2D CAD:	drawings on web pages or in files
3D CAD:	models on web pages or in files
Images:	from internet
Video:	of model making and testing

Table 3.7: Information Carriers used by Student Teams in Studies

Compared with other studies the range of information carriers produced by students is similar to practising engineers (Lowe et al., 2004) but narrower – no memos, faxes, journal/magazine articles and limited meeting minutes.

Information File Formats

Incompatibility of file formats can be an issue due to the variety of ways in which information can be captured digitally. Students tended to use industry standard and generally accepted file formats to support sharing and avoid incompatibility issues. Only in one case did students in a local side of a team have to convert files (*Solidworks*[9] files) to another format (.jpg) to enable their global partners to access and review file content. File formats used by students in this work are noted in Table 3.8.

[9] SolidWorks – CAD design software

Text (with images)	**Image**	**Presentation**	**Spreadsheet**	**Video**
.doc	.jpg	.ppt	.xls	.mov
.txt	.gif	.pdf		.avi
.pdf	.png			
	.bmp			
	.pdf			

Table 3.8: File Formats used by Student Teams

3.3.2.2 Content Analysis Process

Instances of information content were contained in text, images and video. The content of all team online project sites was initially viewed online. Copies of web pages and files (text documents and images) were then printed off and each instance of an information content category was recorded in the margin. See Appendix 3.7 for some marked up examples. Video clips (few and short) were viewed to identify instances of information content. Instances of information content were then counted and transferred to tables in Xcel and totalled. Formal and Informal content, information carriers and file formats were quantified and visualised using bar graphs. System logs and dated entries provided data for case timelines. See Appendix 3.8 for examples of quantifying of data. Email content was examined in a similar manner.

Content Analysis Evaluation

Content analysis gave a very accurate picture of '*what*' information the students had stored. It also provided valuable information on the '*where*' and '*when*' aspects through analysis of system logs and dated entries. Following analysis of the Study 1 cases (Cases 1 & 2), this method was used in preference to using the initial questionnaire as it gave a more accurate picture of '*what*' had been stored, rather than what students thought they had stored. However, Content Analysis was less useful for the '*how*' and '*why*' aspects. Qualitative methods such as questionnaires and interviews were used to gather this type of information.

3.3.3 Questionnaires

In Study 1 questionnaires on information storing practices were issued to UK-sides of teams at a Reflective Session at the end of class and also emailed to participating global USA partners. Only those teams selected for case studies were analysed.

3.3.3.1 Questionnaire Design

Early versions of the questionnaire were trialled with volunteer students. Six questions, relating directly to the thesis research questions, were asked against each of the developed information content categories, and all responses were open-ended. This proved too onerous taking more than twice the estimated time (over two hours); resulting in many repetitive answers; and occasional confusion over the information terminology used. The questionnaire was refined and simplified. Five questions, akin to survey style questions, looked for quantifiable values where students had to tick boxes. Question 4 sought more open-ended responses with student teams giving fuller explanation and rationale. A response for each of the questions was required for different information content categories. See Appendix 3.9 for initial questionnaire.

3.3.3.2 Questionnaire Process

The purpose of the questionnaire and each question was explained to the students at the UK reflective session at the end of the project. In UK local sides, students had approximately 40 minutes to complete the questionnaire. Clarification could be requested at any time. Global partners were emailed the same questionnaire. Questionnaires were then analysed and the results validated and expanded upon by participating UK-sides of teams in semi-structured interviews.

Questionnaire Evaluation and Revised Approach

There were a few issues with the questionnaire used in Study 1 resulting in a different approach for Studies 2 & 3. Firstly the global partners (T6USA) in Case 2 of Study 1 took well over an hour to complete the questionnaire and felt they had to write too much. Without explanation given by the author, and an opportunity for asking questions they had to make some assumptions when responding. USA Team 5 declined to complete the questionnaire due to team time commitments; offering to hold a VC interview with one team member instead. She validated and made comment on UK questionnaire responses; gave the USA rationale for information storing decisions and perceived value for different types of information content. It became apparent on analysis of the questionnaire that examination of the sites gave a more accurate ‘picture’ of the actual information stored. In Studies 2 & 3 the formal questionnaire as a stand alone instrument was abandoned in favour of incorporating the questions into the UK semi-structured interviews for a more efficient process. Study 2 & 3 Global partners (Swinburne and Malta) were emailed a questionnaire; with more open-ended questions relating to the emerging themes. See Table 3.9.

	Questions for Global Partners – Swinburne and Malta	**Response for each information category**
Q1	Please list the +ves and –ves for the information storing tools **(where)** you used to store and exchange information with your global team mates.	open-ended
Q2	Comment on any issues your global team encountered with storing and exchanging information. **(how/why)**	open-ended
Q3	Describe any rules or strategies **(how)** your global team put in place for storing or exchanging information.	open-ended
Q4	In your global team **when** did you store information?	open-ended
Q5	**What** information do you value in a distributed design project?	tick-box (scale – no, some, great value)
Q6	Any other comments?	open-ended

Table 3.9: Questions and Responses Types for Studies 2 & 3

3.3.4 Semi-structured Interviews

The semi-structured interviews involved the UK-sides of teams only due to difficulties in organising conferencing with the 'far sides' of teams due to availability. One USA interview was conducted via *PolyCom*[10] in lieu of a questionnaire. Interviews allowed participants to give their views and opinions freely. Study 1 interviews were designed with the purpose of validating findings from online project sites and the questionnaire. Study 2 & 3 interviews validated the findings of online projects sites and took the place of the questionnaire. This approach proved more valuable and efficient.

3.3.4.1 Semi-structured Interview Design

The interview design included the initial validation of the stored findings and adopted questioning along the lines of inquiry into the thesis research questions. Six key question areas were covered - see Table 3.10. A mock interview, with a volunteer student, was held to pre-test the interview questions; the interview

[10] PolyCom – Video Conferencing system

schedule, estimated timing for activities, questions and the recording equipment. Interview participants were issued with an Information Sheet and Consent Form. See Appendix 3.3.

	Key Questions	Framework for interview questioning
Q1	**Where was information stored?** Confirm where information was stored – refer to *picture of information stored*. Comment	• Any issues with information storing tools used? • Was information easy to find? • Where else did team store information and why? • Satisfied with tools used?
Q2	**What information was stored?** Present what information was stored – refer to charts of Formal/Informal information. Comment.	• Why did you store this information? Satisfaction? • What stored information was looked at during the project? Why? • What was not stored %? And why? • Comment on any information storing issues.
Q3	**How was information stored?** Present the media types used. Confirm media and quantities. +ves, -ves; preference for media; why?	• Did team develop a Distributed Project Information Storing Strategy prior to project work? Were rules established? • Was information organised and structured?
Q4	**When was information stored?** Show timelines and comment.	• Who stored information in the team? • Any patterns formed across team?
Q5	**What value do you give to project information?** Questionnaire written response at interview. For each of the information content types, what value was placed in terms of progressing the project and achieving a common goal, in the context of Distributed/Global Design? Scale of '*no value*', '*some value*' and '*great value*'.	
Q6	**General –** Any further comments on overall experience of distributed information storing?	

Table 3.10: Semi-structured Interview Framework

3.3.4.2 Semi-structured Interview Process

Each UK-side of a global team took part in a semi-structured interview once online project sites had been examined. A visual 'picture' or representation of the stored information was presented to the interviewees (see Table 3.11) and the above questioning framework was used to validate the findings. Interviews took between one hour and one hour fifteen minutes and were recorded using a digital voice recorder and stored electronically. These recordings were transcribed and the transcripts stored as electronic and hard copy Word documents. The transcripts were then coded (according to the earlier categories of *what*, *where*, *when* and *how*) and analysed to identify the issues contributing to the case studies.

Questions (related to research questions)	**Visualisation/Representation of information stored**
Where was information stored?	A diagram showing all technologies used and places information had been stored.
What information was stored?	Bar charts and graphs of the quantities of Formal and Informal information content stored by the team.
What information was **valued**?	Bar charts and graphs of the quantities of Formal and Informal information content valued by the team.
How was information stored?	Bar charts and graphs of the quantities of the information carriers (media) used.
When was information stored?	A timeline highlighting when information had been stored and by whom.

Table 3.11: Data Analysis presented to Students at Semi-structured Interviews

Interview Evaluation

The semi-structured interviews proved both valuable to the interviewer and the interviewees. As expected they afforded validation of the analysis of the content of project sites and provided rationale to *'what', 'where', 'when'* and *'how'* information had been stored in a distributed context. They also engaged the students and the interviewer in a dialogue which allowed additional issues to be discussed and new themes to emerge and be examined. These findings will be explored in Chapter 4.

3.3.5 Examination of Student Reflection and Reflective Reporting

Additional secondary documentation was available in the form of UK class reflection feedback and reflective report writing. UK students (only) were required to undertake this as part of their class assessment. The Global Design Project itself was not assessed. The student reflection and reports of participating teams were examined; key points extracted; and coded. These contributed further to the case study findings.

3.4 Supporting Techniques

Two further research techniques – Clustering and Visualisation using Mindmaps were used to organise the analysis of the findings of the case studies.

3.4.1 Clustering

Clustering is the general name given to the process of inductively forming categories within a context (Miles & Huberman, 1994; LeCompte & Goetz, 1983). It is also sometimes referred to as categorising. Clustering helps reduce, summarise and simplify data and information (Krippendorff, 2004). Clustering was used in the thesis to better understand the emerging phenomenon from the case studies and to bring issues to the 'surface' (Lincoln & Guba, 1985). It also helped categorise and formulate the Principles for distributed-Design Information Storing. General clustering was used as follows –

- *where?* **-** *information storing systems*
- *what?* **-** *information stored and valued*
- *when?* **-** *information patterns, and*
- *how? and why? – project information strategy*

This will be covered in greater detail in the discussion on the case study findings in Chapter 5 and the development of the Principles in Chapter 6.

3.4.2 Visualising information: Mindmaps

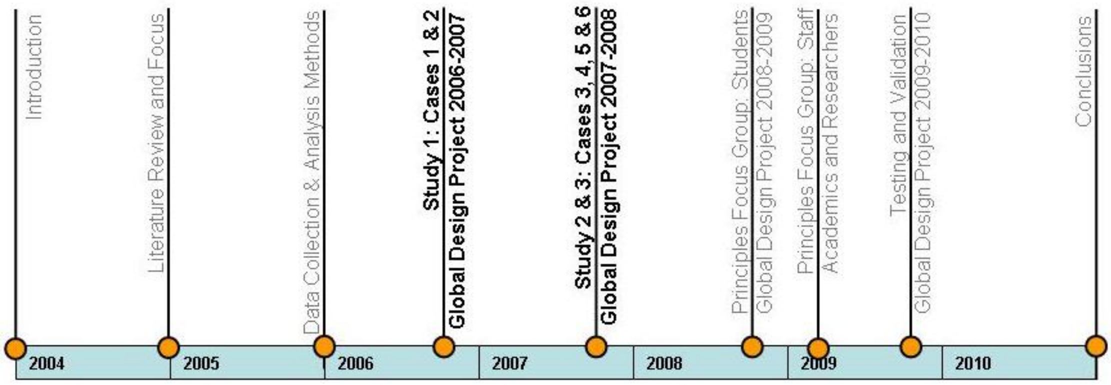
Mindmaps were used to visualise the findings from each of the studies and to compress and order the data. This permitted coherent conclusions to be drawn from the mass of data produced from the case studies (Miles & Huberman, 1994). The Mindmaps for each of the case studies can be found in Appendices 4.8 - 4.13.

3.5 Summary

This Chapter has defined the various methods used to carry out research work into *'How do students store and share design information and knowledge in distributed team-based project work?'* The desire to understand phenomenon within a 'real life' context necessitated the use of the empirical study. Previous studies in engineering design were reviewed and guidance was taken in the determination of the quantitative and qualitative methods to be used. These included the Case Study Method; Content Analysis of data and documents; Questionnaires; Semi-structured Interviews; and Focus Groups. Yin's Case Study Method was used as a basis to establish the information storing of six distributed student teams undertaking the Global Design Project, in order to identify specific issues experienced by students. The need for mixed methods has been established and the research design and process undertaken for each of the methods, as adopted in the research, has been presented. Additional aspects, such as establishing the boundaries to the study; consent; the impact of the studies; coding/classifications; and definitions have been defined. These methods are replicated at Stage 4 of the *Design Research Methodology – Description II/Validation.* This will be reported in Chapter 7 when the validation of the Principles and the Project Memory are presented.

Chapter 4 continues by presenting the findings and results of the case studies, examining what design information and knowledge students in distributed team-based project work stored and shared.

4 Results of Student Team Case Studies



4.1 Introduction

Chapters 4 & 5 address Research Question 1 - *How do students store and share design information and knowledge in distributed design team-based project work?* This Chapter focuses on Stage 2 of the work - *Description I*, the identification of issues and influencing factors that impact on student team-based information storing practices. Over two academic years, six Case Studies examined the information content stored by student global teams during distributed projects. The findings and resulting issues from the Studies, from the analysis of the stored information, the questionnaires, the interviews and the student reflection, are presented in Sections 4.2, 4.3 and 4.4 of this Chapter. Section 4.5 concludes the Chapter with an overall summary. The issues and implications of these findings will be discussed in Chapter 5.

All Case Studies are set in the context of a short Global Design Project. The project gave students the experience of distributed design allowing them to gain an understanding of the problems that can arise. UK students at the University of Strathclyde partnered with students from other universities to form global teams in order to design a product collaboratively. It should be noted that the project outcome was not assessed by any of the participating institutions. Teams were given online tools to manage their distributed project work. See Appendix 4.1 for the context for each Case Study. The original team numbers will be retained throughout the reporting of the results and the discussion. Sources for the findings are indicated in brackets throughout this Chapter using the coding from Appendix 3.4.

4.2 Study 1: Strathclyde/Stanford

Study 1 examined the project information stored by two distributed student teams undertaking the Global Design Project in October 2006, see Appendix 4.1 for details.

Sampling for Study 1

The two cases in this Study were selected from six UK-USA global teams taking part in the 2006-2007 Global Design Project. As a coach to the class, the author was allocated Teams 4 and 6 to supervise. Team 4 included students from a second USA partner, the Franklin W. Olin College for Engineering, Massachusetts, USA, but the lack of approved research consent from their Faculty meant collaborations between Olin had to be discounted for the purposes of this research. Team 4 was subsequently replaced by another Strathclyde/Stanford global team. Study 1 therefore examines the findings for Strathclyde/Stanford Teams 5 and 6.

4.2.1 Case 1: Strathclyde/Stanford Team 5

This project was considered successful, by students, in terms of its product outcome but it was not without issues in terms of storing and sharing project information.

4.2.1.1 Where information was stored?

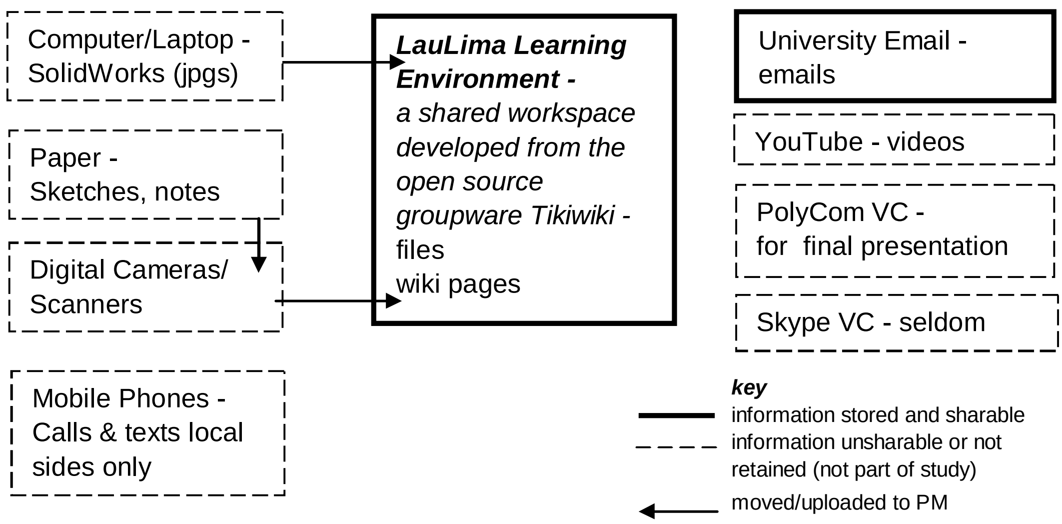


Figure 4.1: Technologies Used and Information Stored by Team 5

Team 5 stored and shared project information in the *LauLima Learning Environment*[11] and University email accounts. Other technologies were used to exchange information (PolyCom VC and Skype[12]) but these did not form part of the study for reasons outlined previously. Figure 4.1 shows all technologies used. Further detail can be found in Appendix 4.2, Case 1.

Feedback and analysis regarding *where* information was stored revealed –

- None of the local communications (mobiles) were retained by the students. (UK,q2)
- Due to time pressure, particularly at the end of the project, emails were used to send information. This was often not uploaded to the online project sites and therefore was lost. (T5,v)
- The wiki pages afforded a place everyone could access at all times. (5.1,rr) The importance of keeping information all together was recognised. (USA,i)
- USA students were less familiar with the *LauLima* system than the UK students causing inequality across the global teams. (T5,v)
- UK students noted a lack of attention was paid to early technology use. (5.1,rr)
- The use of an information storing system with a communication system worked well. (r)

4.2.1.2 What information was stored?

The project information in Team 5's *LauLima* file galleries, wiki pages and emails was examined. See Appendix 4.3, Case 1, for data.

In LauLima File Galleries

More Formal information content (80%) was stored in the files than Informal (20%), see Figure 4.2, (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 1, content in files.

[11] LauLima Learning Environment - a shared workspace and digital library developed at the University of Strathclyde from the open source groupware Tikiwiki. Students used the shared workspace element which consisted of file galleries and wiki pages.
[12] Skype – web-based desktop conferencing tool incorporating 'chat' and video.

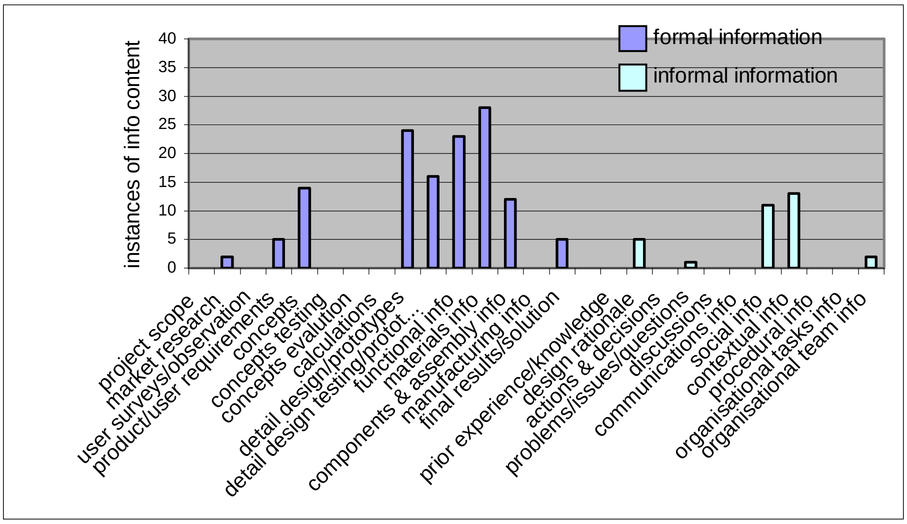


Figure 4.2: Instances of Information Content in Team 5 Files

On LauLima Wiki pages

More Formal information content was stored across all wikis (**60%**) than Informal information (40%), see Figure 4.3, (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 1, content in wikis.

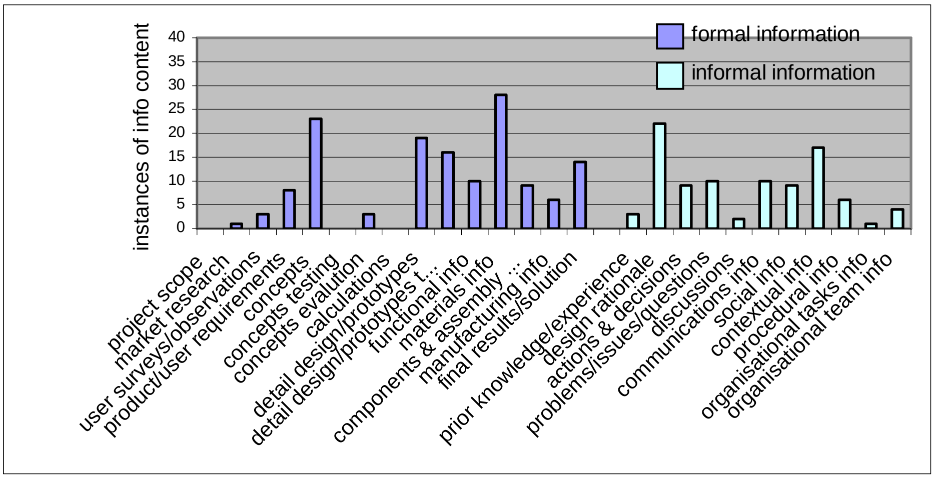


Figure 4.3: Instances of Information Content in Team 5 Wikis

In Emails

Informal information content accounted for **99%** of instances of stored information in emails. All types of Informal information content were found, see Figure 4.4, (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 1, content in emails.

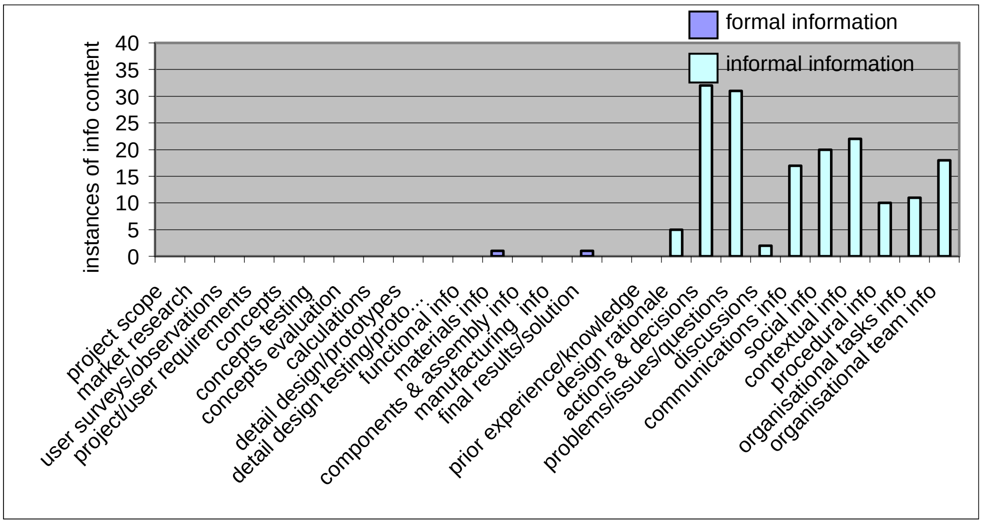


Figure 4.4: Instances of Information Content in Team 5 Emails

Amount of Information

Overall, the information content across the files, wikis and emails evidenced **slightly more instances of Informal information** (**52%**) than **Formal** (**48%**), see Figure 4.5. This highlighted the value of email use to add informal information to project work. Overall, UK students stored most instances of information content in the files (52%) and on the wikis (74%) but the USA students stored more instances of information content in the emails (65%).

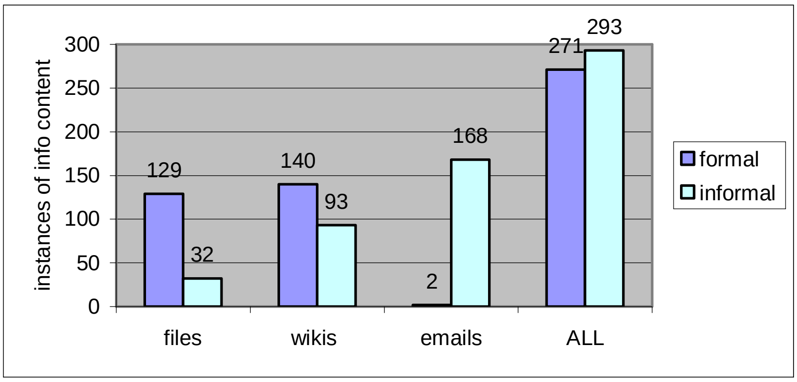


Figure 4.5: Team 5 Formal and Informal Info Content across Files, Wikis and Emails

Feedback and analysis regarding *what* information was stored revealed -

- Students thought they had stored a greater percentage of Formal information throughout the project. (UK,q1) Overall this was not the case.

- Students noted wikis were used to keep everyone aware of what was happening (UK,q4), for example, through *design rationale*, *actions & decisions* and *communication information.* (UK,q2)
- Not all project information produced by the team was stored or shared. USA students noted this would be '*overkill*' (USA,i). UK students found that storing information took time and at times this took over from 'doing' the project. (T5,v) For percentage amounts of each type of information content the UK-side thought they stored see Appendix 4.5. The USA-side did not complete a questionnaire.
- The questionnaire highlighted that some students were not exactly sure what information they might need and there was an anxiety to store more than they needed in case it became important later on. (UK,q4)
- Students felt that not enough *actions & decisions* had been recorded –

  "…we stored more about the actual product and concepts than the actual path to get there." (T5,v)

- Time was an important factor in terms of what students might store. On a short project they stressed there wasn't enough time to record too much. (UK,q4) However, on longer projects it was crucial to store adequate information to support remembering. (T5,v)

Information Carriers (Files)

Information was **richest as images** in the file galleries. Of the information content instances analysed in the files, 98.5% were in images and 1.5% in text. For more data on information carriers see Appendix 4.6. For different information content stored in files see Figure 4.6.

Feedback and analysis regarding *information carriers* revealed –

- Images were a useful and quick way to store information. Both USA- and UK-sides worked well this way. (T5,v)
- Concept generation was predominantly stored on paper as *hand drawn sketches/notes*. These were scanned or photographed for storing. (UK,q4) Students noted this was the quickest way to record most design information.
- *Physical models* were photographed and video was used to record *detailed design/prototypes* and the *final results/solution*. (UK,q3)

- Images of sketches, models and prototypes were the most useful information carriers. These were good evidence to show to others and also gave a snapshot of what happened. (UK,q4)

  "a great way of storing information …all of the information that is hard to put into other forms…" (USA,i)

- Students reported that video was useful for the sharing of model making and testing; but they found it was time consuming to produce and upload. It was also hard to find specific information in video later on. (UK,q4)

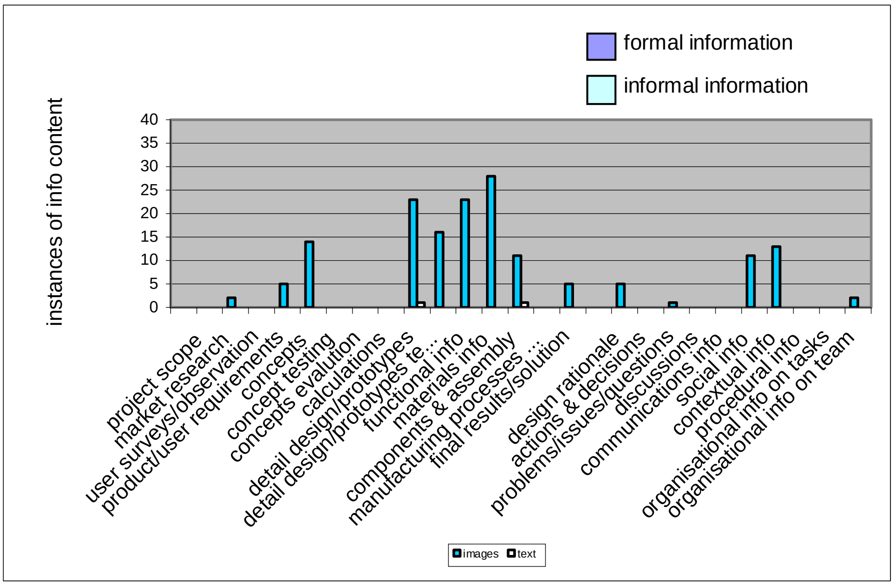


Figure 4.6: Instances of Information Content in Team 5 Files by Information Carrier

4.2.1.3 When information was stored?

File Gallery Timeline

Examination of file uploads identified peaks of activity at and just following weekly deliverables. See Figure 4.7.

Wiki Timeline

Wiki activity was more consistent throughout the project but also evidenced peaking at new stages and deliverable dates. Activity was highest at the final week since Team 5's wiki pages were used as their final presentation. See Figure 4.8.

Email Timeline

Emails were exchanged regularly throughout the work, commencing about a week before the project started until it completed. See Figure 4.9.

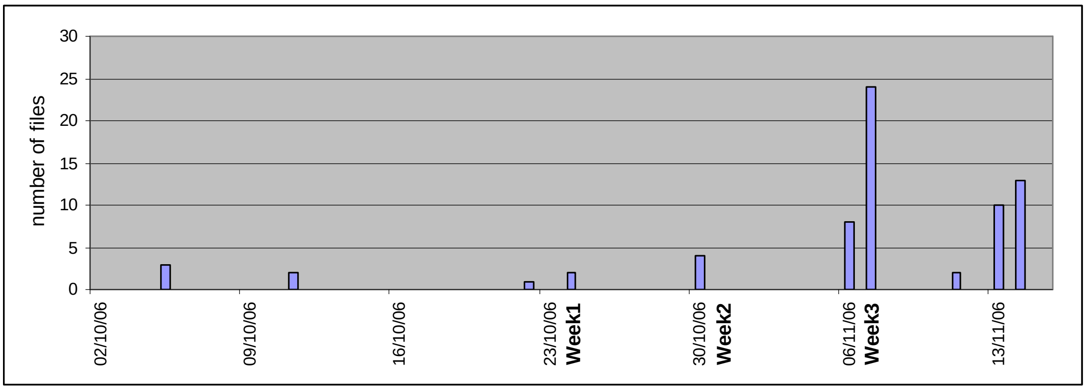


Figure 4.7: Team 5 - Files uploaded over time

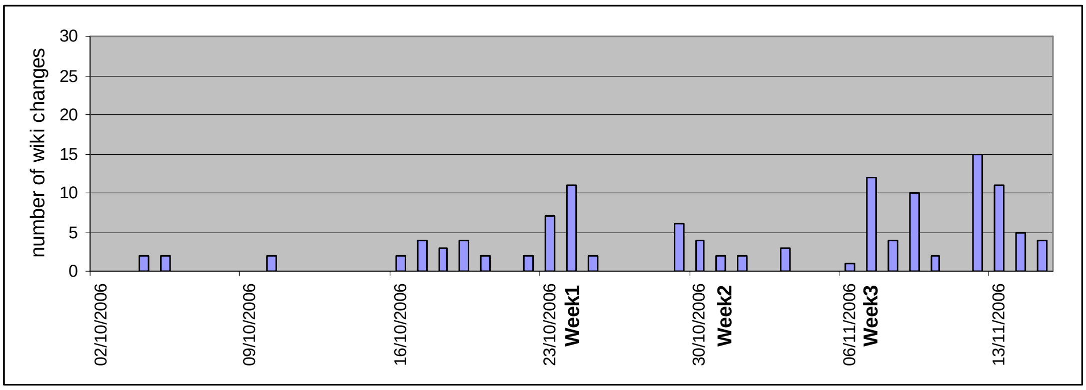


Figure 4.8: Team 5 - Wiki changes over time

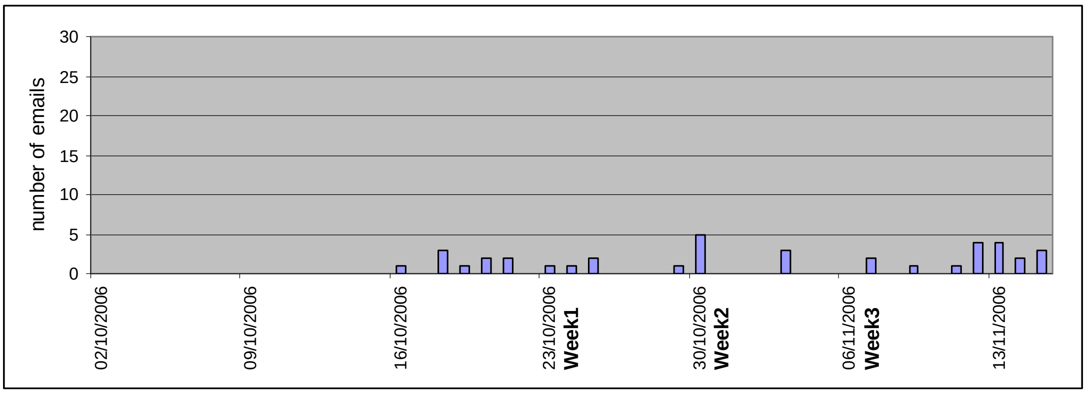


Figure 4.9: Team 5 - Emails sent over time

Feedback and analysis regarding *when* information was stored revealed -

- UK activity was high at the start of Week 1, with UK students setting up the online project site. (fg,w)
- The USA students spent time familiarising themselves with *LauLima*. Their contribution was low at first but rose by Week 3. (USA,i)
- Each side of the team stored information at different times. UK-side stored information as they went along. USA-side stored information later, meaning some decisions were taken without all available information. (T5,v)

4.2.1.4 How information was stored?

Feedback and analysis regarding *how* information was stored revealed -

- Information storing evolved; no plans were made. The USA-side noted that on reflection a strategy should have been discussed early on.

  > *"A scheduled way of storing would help minimise problems with information storing."* (USA,i)

  UK students recognised, in hindsight, that they needed to organise and structure information in order to work smoothly. (5.1,rr) Developing guidelines might also have been a good icebreaker. (T5,v)
- The UK students created the team file galleries, but reported they should have made joint rules for storing information at the beginning, to allow for greater ownership across both sides of the team. (T5,v)
- Students regarded the sharing and storing of information important for a number of reasons – for everyone to have access to up-to-date project information; for decision making; progressing the project; to support referring back; and for presentations. (q4) Students noted that information recorded would refresh their memories, for example, progressing the project and report writing. (5.1,rr)

4.2.1.5 Information Valued by students

The UK students *'greatly valued'* the Formal information more than Informal information. (UK,q5) Whilst the USA students confirmed valuing similar Formal information content types to the UK students, they *'greatly valued'* the Informal information more. *Actions & decisions* and the *problems/issues/questions* were recorded the most. For greater detail see Appendix 4.7.

4.2.1.6 Summary of Findings from Study 1 Case 1

Several key issues emerged from examining Case 1 –

- Information was stored in different places resulting in students sometimes not knowing where information was.
- Not enough time was given to the use of the technologies.
- Unequal competency in the use of the information storing technology across the team resulted in unequal contribution of information to the online project site. This was perceived as a lack of engagement.
- Email was used at the beginning to socialise; to send information for speed; and at the end to complete the project task. When information content in emails is added to the information content in the files and wiki pages, then Informal information content is greater.
- It took time to store information.
- Students reported they did not refer back to stored information often.
- An information storing strategy for progressing the project should have been discussed.
- Information was sometimes stored in 'temporary' locations; for example video was stored in *YouTube*, leaving gaps in records.
- Questionnaire responses and discussion at interviews highlighted that students needed some guidance on what to store to increase project performance and efficiency.

A summary of all findings from Case 1, in relation to the research questions and clustering, can be found in a Mindmap, in Appendix 4.8 and will be discussed in greater depth in Chapter 5.

4.2.2 Case 2: Strathclyde/Stanford Team 6

Issues with information storing in this team caused frustration and impacted on the quality of the final product outcome. Lack of familiarity with tools led the USA-side of the global team to use another system. See Appendix 4.1 for Case Study 2 context details.

4.2.2.1 Where was information stored?

The main repository for Team 6's distributed project information was the *LauLima Learning Environment* and University email accounts. *Socialtext*[13] content was not quantified as this was already stored in *LauLima*. Further detail can be found in Appendix 4.2, Case 2. All other technologies used (including *PolyCom* and *FlashMeeting*[14]) can be found in Figure 4.10.

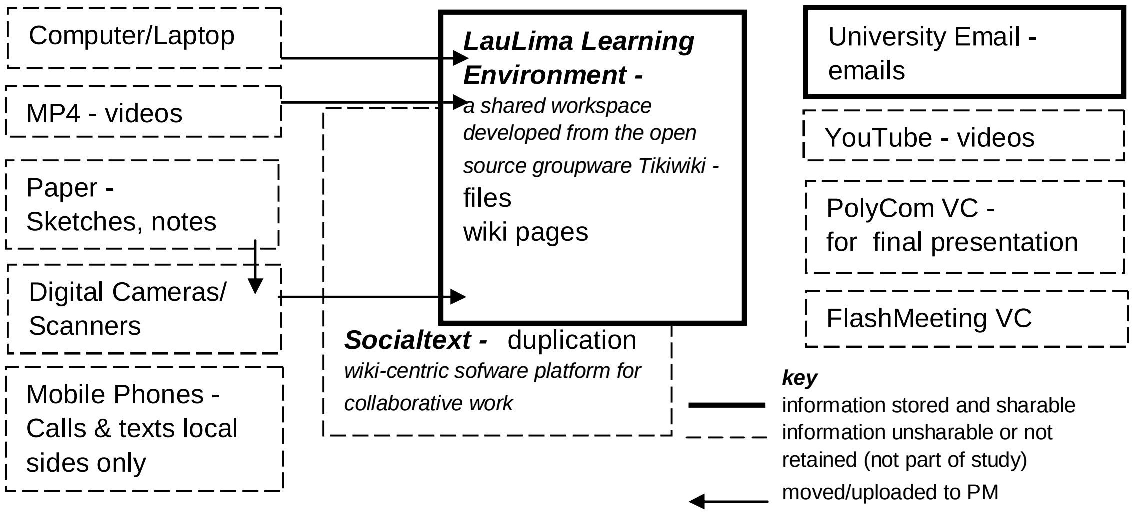


Figure 4.10: Technologies Used and Information Stored by Team 6

Feedback and analysis regarding *where* information was stored revealed –

- Project information was organised and stored in different places, leaving uncertainty as to where information was; with team members not finding what they wanted easily. (6.1,rr)

  > *"We had too many systems….it was too fragmented..." "…it kind of got to the point you were looking everywhere for information…and wasting time."* (T6,v)

- University email contained valuable project information. UK students reported that email was their most used tool. (6.1,rr). They used it everyday and were used to it; *"…check on a kind of daily basis. It was part of our routine"* (T6,v).
- Local sides communicated by mobile and text but not across team due to cost. (T6,v)

---

[13] Socialtext – a wiki-centric platform for collaborative work.

[14] FlashMeeting – an online meeting application allowing dispersed groups of people to meet from anywhere in the world with an internet connection; consists of audio, video and chat.

- The USA-side found it difficult to master the *LauLima* system before the project start. They adopted another more user-friendly tool – *Socialtext* (r), only informing their UK partners midway on the project. This change of technology and lack of communication caused confusion.

4.2.2.2 What information was stored?

The project information in Team 6's LauLima file galleries, wiki pages and emails was examined. See Appendix 4.3, Case 2, for data.

In LauLima File Galleries

A greater amount of Formal information content (68%) was stored in files than Informal (32%), see Figure 4.11, (Appendix 4.3 for instances). See Appendix 4.4, Case 2, for the top five information content types stored.

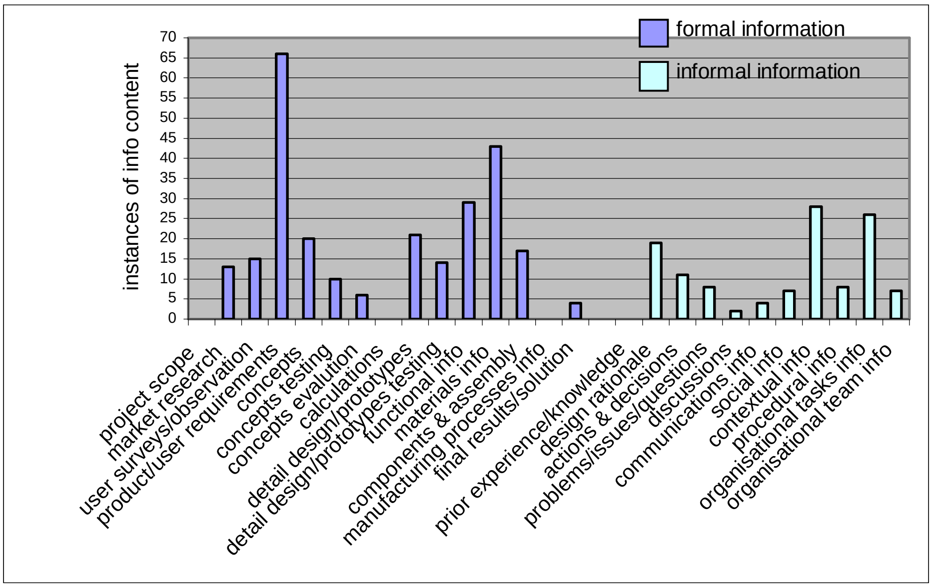


Figure 4.11: Instances of Information Content in Team 6 Files

In LauLima wiki pages

100% of the instances of information content found in the wiki pages was **Informal**, see Figure 4.12, (Appendix 4.3 for instances). The most commonly occurring Informal information content stored was *contextual information*. For more detail on the top five information content types stored, see Appendix 4.4, Case 2, content in wikis.

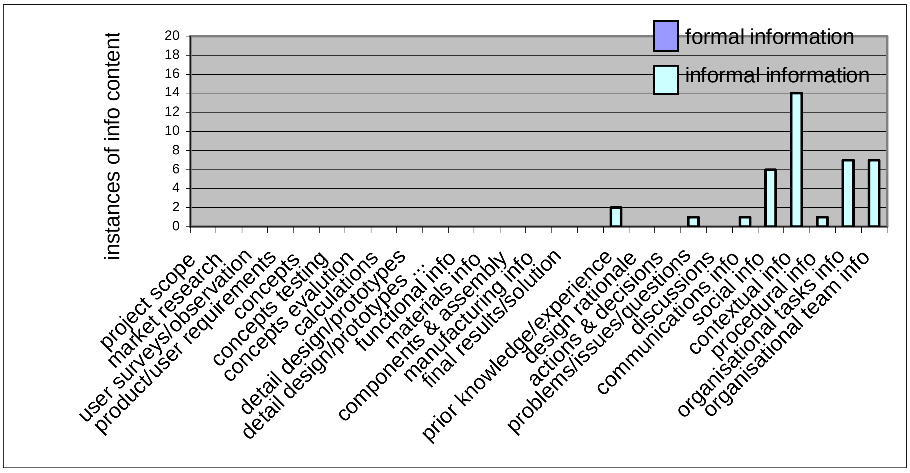


Figure 4.12: Instances of Information Content in Team 6 Wikis

In Emails

More **Informal information content (85%)** than Formal (15%) was stored in emails. Stored Formal information content stored low, mainly about the *final result/solution*. See Figure 4.13, (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 2, content in emails.

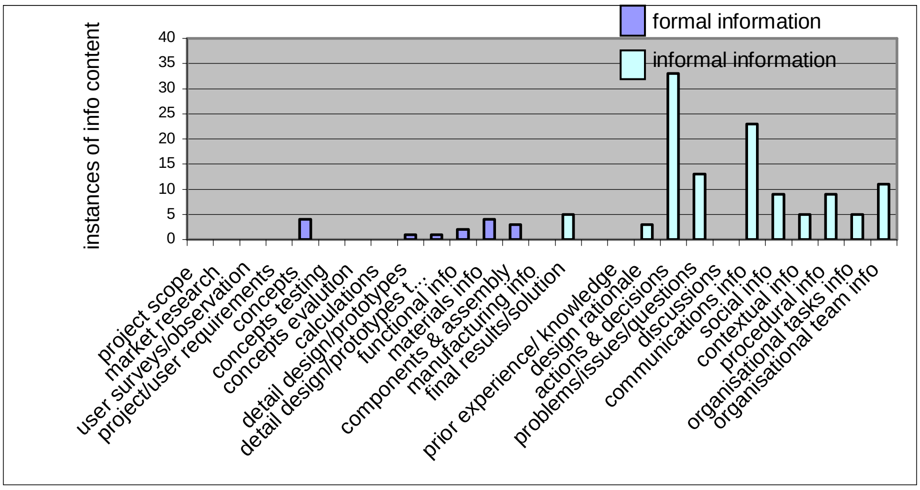


Figure 4.13: Instances of Information Content in Team 6 Emails

Amount of Information

Overall, the combination of the content in the files, wikis and emails evidenced **only slightly more instances of Formal information (51%)** than Informal (49%), see

Figure 4.14. This was the expected outcome. Students used the file galleries to store their more formal project outputs and deliverables; whereas, wikis were used to point to other information like a contextual framework. Emails contained more of the informal conversational and organisational activities of the project. Overall, UK students stored most instances of information content in the files (98%); on the wikis (68%) and in the emails (69%).

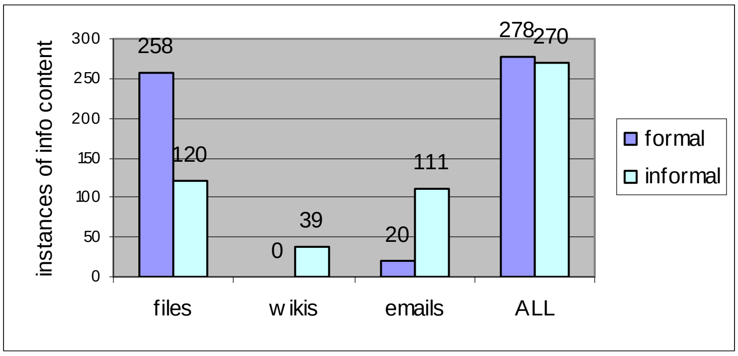


Figure 4.14: Team 6 Formal and Informal information across Files, Wikis and Emails

Feedback and analysis regarding *what* information was stored revealed –

- UK and USA students thought that they had stored more Formal information content throughout the project but overall Informal information content was almost equal to the Formal information content. (fg,w,em)
- Students reported they found recording the Informal information time consuming, especially on such a short project. (UK,q4)
- Students recognised that not all information could be stored with time being a factor especially on short projects. For percentage amounts of each type of information content the team thought they stored see Appendix 4.5. Close examination of the content of their files, wiki pages and emails, against what students thought they had stored, however showed some inconsistencies. For example, both UK and USA students noted they had not stored any *functional information*, *social information* or *contextual information*. (UK,USA,q) Data analysis evidenced instances of each. (fg,w,em) As such, in the further Studies 2 & 3, students were only asked for an overall percentage of the amount of project information they thought they had stored from everything generated. They were then shown the analysis of the findings of the stored information content in their

Project Memories and asked to confirm the findings and give supporting rationale.

- A new information content category was discovered when analysing the information in student online project sites – *locational information*. This information content gives advice and direction to where information is stored. Students found this very useful. This information content category was added to the original content classification scheme. (T6,v)

Information Carriers (Files)

Text contained the most instances of information content (76%). (fg) **Images** contained 8% of information instances and provided Formal information content on *materials, detail design/prototypes* and their *testing;* and Informal information content on *contextual information* and *social information*. One **presentation file** contained 12% of information content, with more instances of Formal information content and limited Informal information. The five **video files** contained mainly Formal information content on *detail design/prototypes;* and their *testing.* (fg) See Figure 4.15. For more data on information carriers see Appendix 4.6.

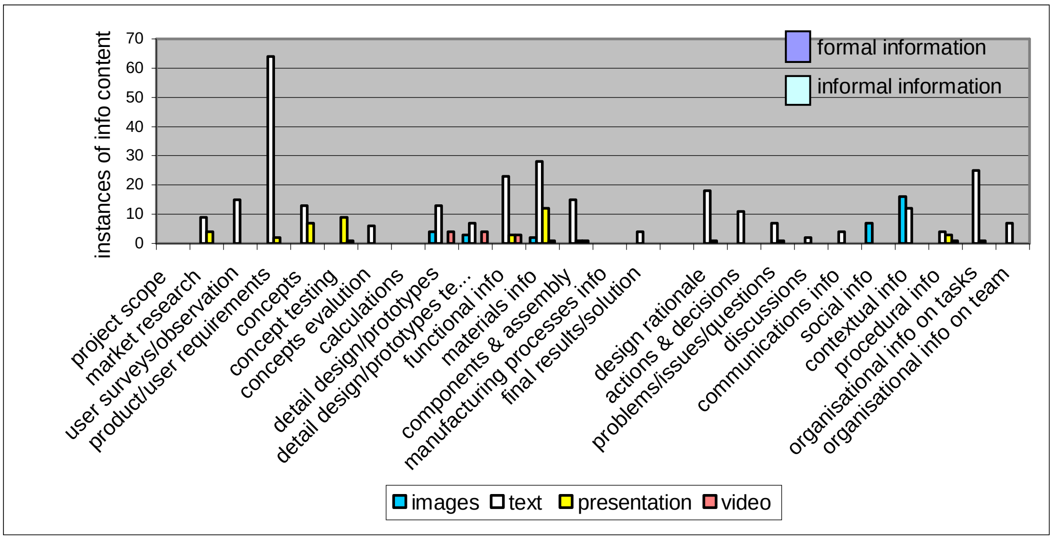


Figure 4.15: Instances of Information Content in Team 6 Files by Information Carrier

Feedback and analysis regarding *information carriers* revealed –

- Early on information was mainly informal (*contextual* and *social information*). *Market research* was stored in Word docs. Concepts were stored as hand drawn sketches or notes and scanned or digitally photographed. Students found scanning sketches simple, giving good quality. (UK,q4)

- *Design rationale, actions & decisions, discussion* and *communications information* were summarised and stored in reports and meeting minutes, as Word docs. (UK,USA,q3)
- Photographs and video captured the information in the prototypes. Students found video to be a good way of sharing information but production and viewing were time consuming. (UK,USA,q4;T6,v) *Social information* in video and photographs, helped to build team cohesion. (w;UK,q3,q4)
- *Final results/solution* were captured as scanned sketches and photographs and videos of models/prototypes and presented in a PPT via VC. (UK,q4)

4.2.2.3 When information was stored?

File Gallery Timeline

Distinct peaks of upload activity to Team 6's file galleries occurred at the beginning of the project and at the weekly project deliverables. See Figure 4.16.

Wiki Timeline

Wiki use was low on the project but more frequent and also peaking (to lesser extent) around deliverable times. Wiki use was slightly more evenly spread across the project. See Figure 4.17.

Email Timeline

Examination of emails showed they were used predominantly at the beginning of the project and at the end; to initiate collaboration and to finish project following confusion over where information was stored. See Figure 4.18.

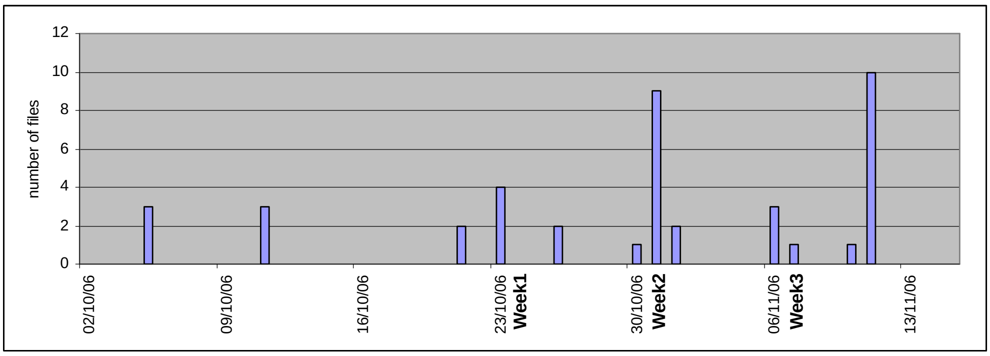


Figure 4.16: Team 6 – Files uploaded over time

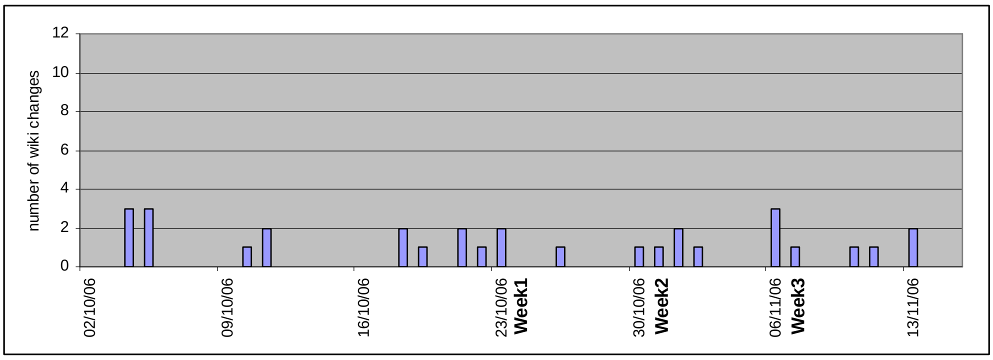


Figure 4.17: Team 6 – Wiki changes over time

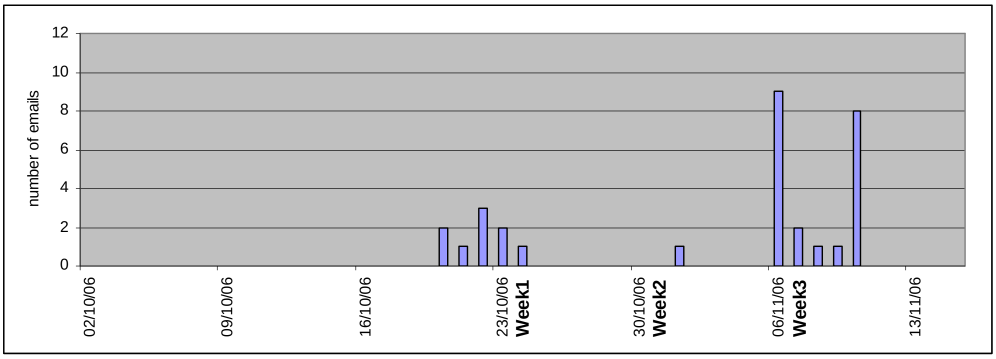


Figure 4.18: Team 6 – Emails sent over time

Feedback and analysis regarding *when* information was stored revealed -

- *LauLima* wikis were maintained by the UK students, with USA students only contributing to wikis during training and once during the project. (v)
- Email content was mainly about managing the project - *communications information*, *procedural information*, *actions & decisions* and *organisational information on tasks* and *team*. (em)

4.2.2.4 How information was stored?

Feedback and analysis regarding *how* information was stored revealed -

- Rules for information storing were not considered. Information storing simply happened. Students agreed, during the UK reflection and interview, that it was a mistake not to discuss and record the ‘rules’ before starting. Many of the issues they experienced would have been avoided by doing this. (6.1,6.3,rr) Things would have run much smoother with an information strategy. (T6,v)
- Team 6 file galleries and emails had no organisation or structure. The wikis however, had structure with levels and were used to point to documents in the file galleries, by key project stages and deliverables. (T6,v)
- Students noted *market research* was stored in order to share background to the project. *Product/user requirements* were stored so that there was a key set of requirements for everyone to work to. Students did note though, that these were not always referred back to. (UK,USA,q4)
- *Concepts* were regarded as an important element to share and discuss for a shared understanding. *Design rationale* was recorded in the deliverables throughout the project to show everyone how decisions had been made. (UK,q4,q6)
- Students found c*ontextual information* harder to formalise and often had not realised they were storing this type of information content. (USA,q4)
- Key points from *discussion*s and *problems/issues/questions* raised at meetings (including VCs) were minuted, typed up and stored as Word docs on *LauLima* so they could be shared with everyone. (UK,q4)

4.2.2.5 Information Valued by students

The UK students gave more value to the Formal information; the USA-side valued Informal information more. See Appendix 4.7. This was as a result of each side pursuing slightly different project objectives; with the UK students focused on producing a product outcome and the USA-side interested in exploring project processes. (USA,q5).

The value students attached to information did not necessarily mean it was stored. For example, UK students gave no value to *problems/issues/questions* or *social* *information* but stored twenty two instances each of this information content in order to maintain project progress.

4.2.2.6 Summary of Findings from Study 1 Case 2

The key issues emerging from Case 2 are –

- Lack of familiarity with the technology caused the USA students to use another simpler tool. This contributed to duplicated information in different places adding to the confusion. This further contributed to a lack of communication during the project.
- Project information stored over too many technologies resulted in fragmented project information with students becoming frustrated.
- Differing skill levels with the technology, resulted in inequality across the team. Insufficient time was afforded to allow sufficient familiarisation with tools.
- In times of difficulty students resorted to email to exchange project information. Most was later transferred to the central shared workspace but could have been lost.
- Team 6 had no rules in place for information storing. They later agreed this was erroneous.

Many of these issues impacted to produce a poorer quality product outcome. A summary of all findings from Case 2, can be found in a Mindmap, in Appendix 4.9. This will be discussed in greater depth in Chapter 5.

4.3 Study 2: Strathclyde/Swinburne

Study 2 examined the project information stored by two student distributed teams on the Global Design Project in October 2007, see Appendix 4.1 for details. Note that the Swinburne students were within weeks of completing their degree programme which impacted engagement to some extent towards the end of the project. Study 1 identified the need for simple, easy to use systems. Based on this, each distributed team was assigned technologies by teaching staff to manage distributed information.

Sampling

The two cases in this Study were selected from six Strathclyde-Swinburne global teams. The author was allocated Teams 2, 3 and 5 to supervise. Teams 2 and 3 were selected since the tools they were assigned, *Socialtext* (Team 2) and *Google Docs* (Team 3), were regarded more as centrally shared workspaces than *YouTube*.

4.3.1 Case 3: Strathclyde/Swinburne Team 2

Students reported the project to be a worthwhile experience with only a few information storing issues during the project. A good product outcome was achieved.

4.3.1.1 Where information was stored?

Team 2's project information was shared and stored in *Socialtext*; on wikis as *text* or as *photographs of physical models/objects/people*. Figure 4.19 shows all technologies used by Team 2. Further detail can be found in Appendix 4.2, Case 3.

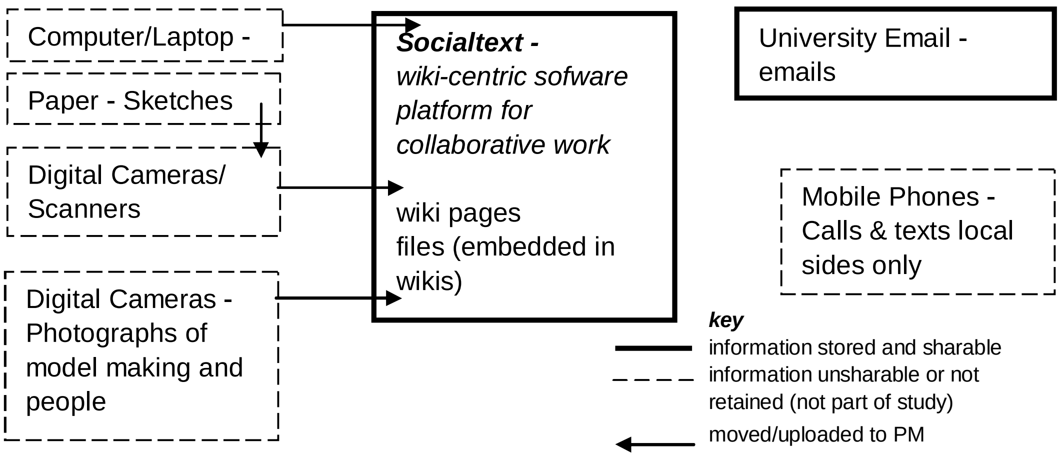


Figure 4.19: Technologies Used and Information Stored by Team 2

Feedback and analysis regarding *where* information was stored revealed -

- All students found *Socialtext* had an acceptable learning curve; it was simple to use; posting and viewing information was easy. (2.1,*rr*; 2.1,v;2.2,v;Swq) Initial issues with signing up; setting shared permissions and locating information were quickly overcome by using email. (2.1,v;2.2,v;Swq)
- Team 2 used a time-limited trial version of *Socialtext*, forgetting to back up project information. On reflection the Strathclyde students noted they would now be wary of any short-term information storing solutions. (2.2,v)
- Strathclyde students found the quickest method of storing and sharing concept information was as photographed sketches uploaded to wikis. (2.2,v)
- Swinburne students photographed their development and prototyping. (Sw,q)
- Email was used at the project start for team introductions and to help set up the *Socialtext* shared workspace. Communications then moved to *Socialtext*. (T2,v)

4.3.1.2 What information was stored?

Team 2's project information lay on *Socialtext* wiki pages and in emails. All stored files were embedded in *Socialtext* wiki pages and were therefore not quantified twice. See Appendix 4.3, Case 3 for details.

On Socialtext wikis

Almost equal amounts of Formal information content (51%) and Informal information content (49%) were stored on wikis, see Figure 4.20 (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 3, content in wikis.

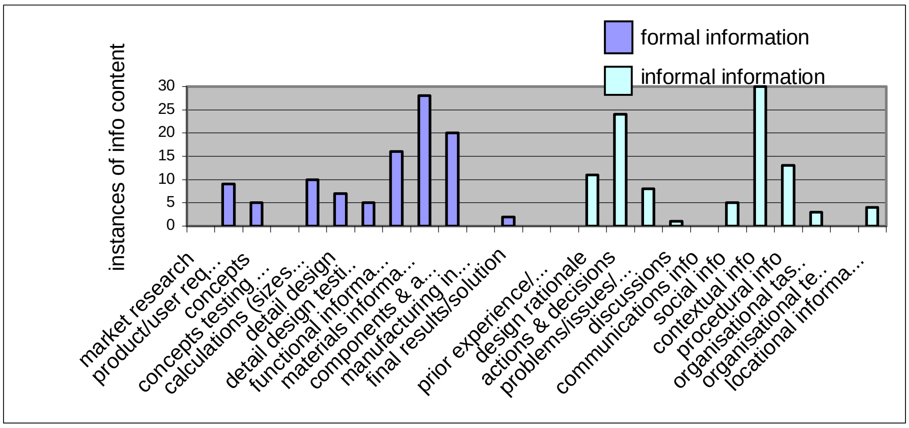


Figure 4.20: Instances of Information Content in Team 2 *Socialtext* Wikis

In Emails

100% of information content in emails was **Informal**, see Figure 4.21 (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 3, content in emails.

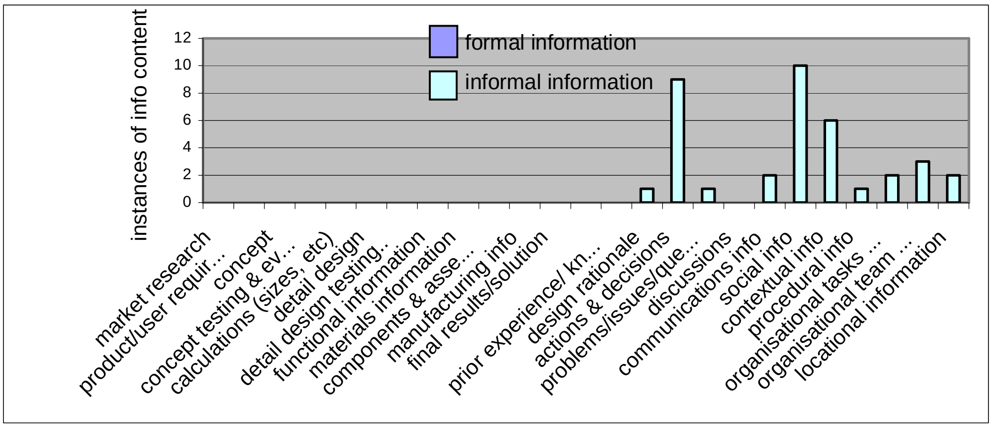


Figure 4.21: Instances of Information Content in Team 2 Emails

Amount of Information

Overall, the content in the wikis and emails evidenced **more instances of Informal information (57%)** than **Formal (43%)**, see Figure 4.22. Strathclyde and Swinburne sides stored almost equal amounts of information content in *Socialtext* - 54% and 46% respectively. Strathclyde sent 80% of emails and Swinburne 20%.

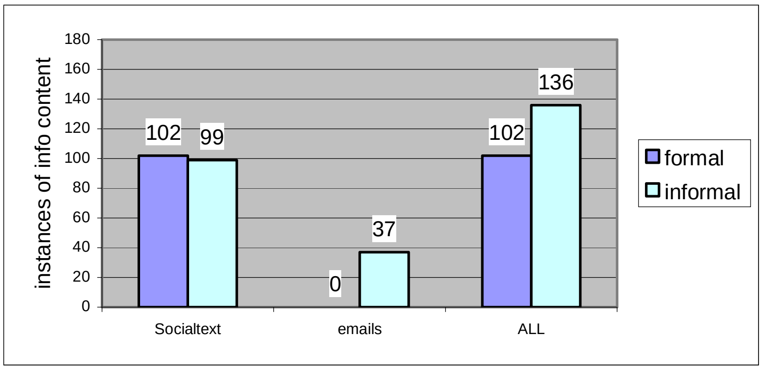


Figure 4.22: Team 2 Formal and Informal information across *Socialtext* and Emails

Feedback and analysis regarding *what* information was stored revealed -

- At interview it was noted that such high numbers of instances of informal information content had not been expected by students. (2.2,v)

- UK students noted that asynchronous working required greater description and more detailed explanation. Students took a step-by-step approach, storing more *actions & decisions* and *contextual information* than in conventional work. (T2,v)
- The importance of *contextual information* was recognised. (2.1,2.2,v) During the Global Design Project, the Swinburne students were a few weeks away from their final exams, which contributed to low communication. Strathclyde students felt this was the kind of *contextual information* that should have been shared. (T2,v)
- UK students noted that not all project information was stored: overall about 60-70%. (See Appendix 4.5) Students felt that not all early concepts on paper required storing and sharing. They would not store *discussions;* only summarising relevant ones. They recognised a need to store some *problems/issues/questions* which might otherwise halt progress. (2.1,2.2,v)
- *Locational information* was stored since it was crucial to know where information was and to find it easily. (2.1,2.2,v)
- Each local side tended not to revisit their own stored project information but viewed and discussed their global partner's stored information. (2.2,v)

Information Carriers (in Socialtext)

Two information carriers were used to store project information - **text** and **images**. 62% of instances of information content were stored as *text* and 38% in *photographs of models/objects/people*. See Figure 4.23. For more data on information carriers see Appendix 4.6.

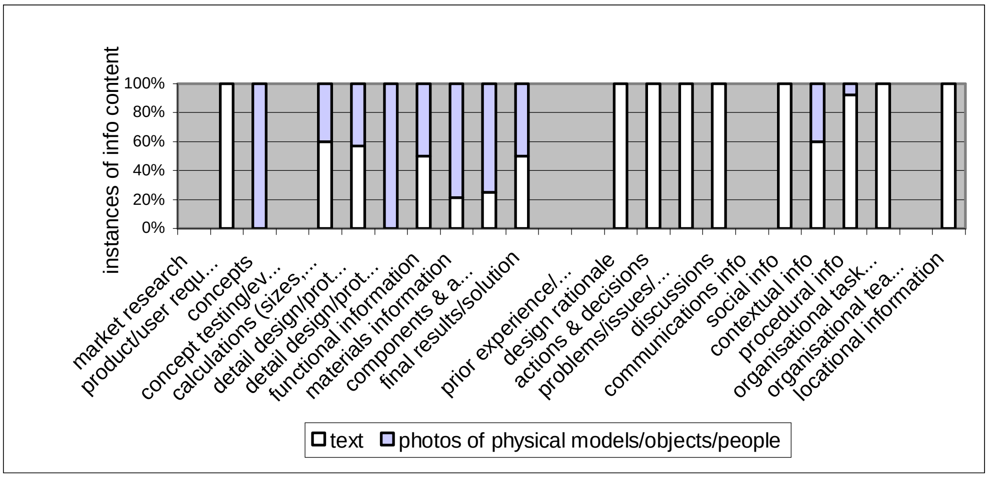


Figure 4.23: Instances of Information Content in Team 2 *Socialtext* site by Information Carrier

Feedback and analysis regarding *information carriers* revealed -

- P*hotographs of physical models/objects/people* showed working methods; various stages of prototyping; and the assembly and function of the coffee cup holder. (T2,v)
- Photographs were used to record information content due to simplicity, speed and clarity. An informative photograph with a few bullet points explaining details was most ‘natural’ to the students. (2.2,v)

4.3.1.3 When information was stored?

The task-based, ‘follow-the-sun’ nature of the project affected when information was stored. It was stored following tasks and rather infrequently. See Figure 4.24.

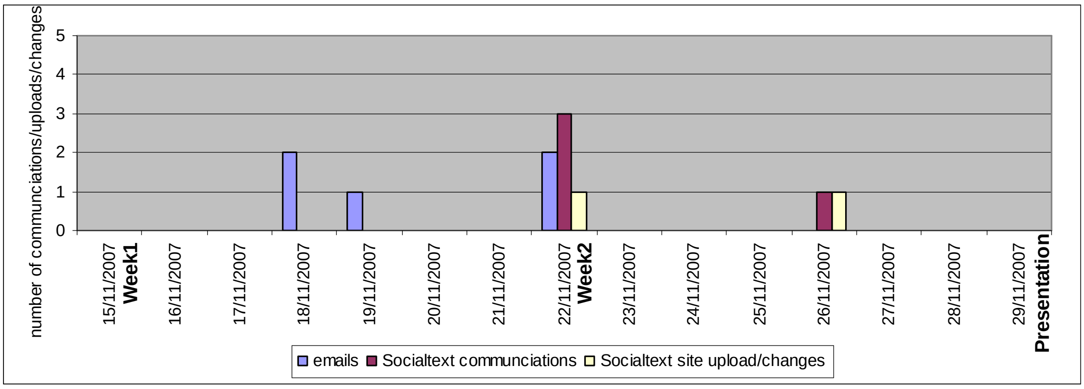


Figure 4.24: Team 2 - All Content Stored over Time

Feedback and analysis regarding *when* information was stored revealed –

- The project started with informal email team introductions. (2.2,rr)
- Work was shared and handed over by each local side of the team on completion of tasks. Little information was shared globally during each collocated element of the work creating a distinct start-stop pattern to project work. (r;2.1,rr;2.2,v;Swq)

4.3.1.4 How information was stored?

Feedback and analysis regarding *how* information was stored revealed –

- No strategy or joint rules for storing project information were prepared. UK students gave reasons: firstly the nature of the task-based, ‘follow-the-sun’ work mode meant information was stored by each side after completion of tasks. The

UK-side started and the Swinburne students copied the format for consistency. Secondly, students found storing information chronologically on wiki pages to be clear and structured thus not needing rules or a strategy. Thirdly, the Strathclyde students didn't feel they knew the Australian students well enough to discuss a strategy. (2.2,v;Swq;r;2.2,rr)

- During reflection the UK students recognised the need, when working asynchronously, to make information clearer which they noted took time and required additional effort when compared to collocated work. *"This forced our side of the team to think harder."* (2.2,rr)

4.3.1.5 Information Valued by Students

All categories of information content were either *'greatly valued'* or given *'some value'* by all the students, except for *social information*. See Appendix 4.7 for detail.

Feedback and analysis regarding the *value* of information revealed –

- Strathclyde students did not value *social information*; putting this down to a lack of collaboration. (UK,q)
- Strathclyde students also found *locational information* was of *'great value'* –

  "There's nothing more frustrating than someone sending you a file and you don't know where it is." (2.1,v)
- *Design rationale, discussions,* and *organisational information on team* were Informal information types *'greatly valued'* in terms of progressing work. (UK,q)
- D*esign rationale* was really important in terms of justifying why something had been done. (UK,q;Swq;2.2,2.1,v)
- Information content that students valued wasn't necessarily what they stored on the project. Both Strathclyde and Swinburne sides valued *market research* and *organisational information on team* '*greatly*' but neither of these categories were stored. Time was given as the factor. (UK,q;Swq)

4.3.1.6 Summary of Findings from Study 2 Case 3

A few specific issues arose from the examination of Case 3 –

- Team 2 stored and shared information with each other side only once a task had been completed. This contributed to a poor collaborative working experience, but at the same time not a poor collaborative output.

- Students used a time-limited trial version of *Socialtext*; resulting in stored project work being unavailable to UK students for writing reflective reports weeks later.
- Only once familiar with the system was it easy to use and find information.
- Students found that in asynchronous design information had to be concise and clear. This took time and additional effort compared to collocated work making students think harder.
- Students did not realise how much Informal information they had stored.

A summary of all findings from Case 3 can be found in a Mindmap in Appendix 4.10. All findings and issues will be discussed in greater detail in Chapter 5.

4.3.2 Case 4: Strathclyde/Swinburne Team 3

Students reported the project to be a valuable experience. Information storing issues tended to be at the start of the project due to unfamiliarity with technology. See Appendix 4.1 for case study context details. All findings are reported below.

4.3.2.1 Where information was stored?

Team 3 used *Google Docs*[15] to store and share information. Information also lay in emails. See Figure 4.25 for technologies used.

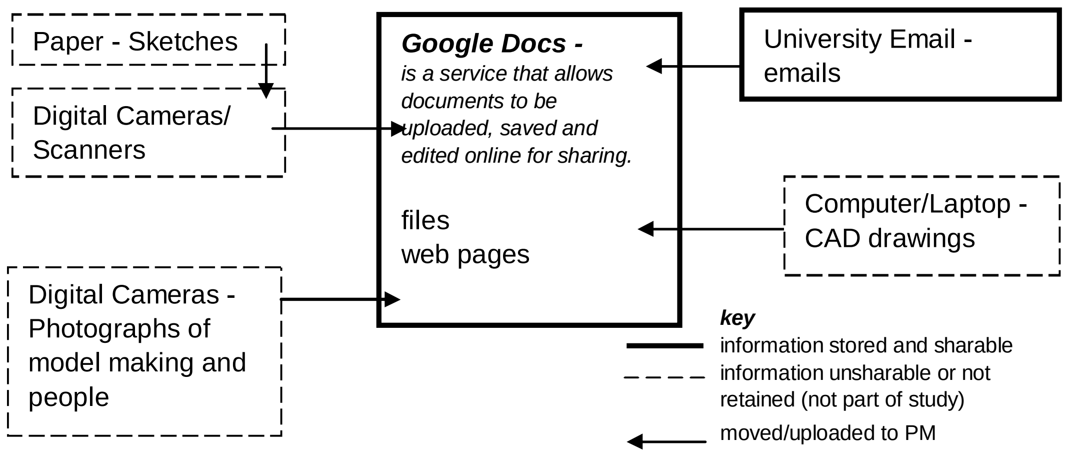


Figure 4.25: Technologies Used and Information Stored by Team 3

[15] Google Docs - a web-based service that allows documents to be uploaded, saved and edited online for sharing.

Feedback and analysis regarding *where* information was stored revealed –

- Students reported that insufficient time was allowed to familiarise themselves with *Google Docs* prior to starting the project, causing access issues and initial confusion over the location of stored information. (3.1,v)
- Students reported *Google Docs* was easy to use. It was efficient; information was easy to find; it suited project needs by providing sufficient space and allowed everyone access to project information regardless of location. (3.1,rr;Swq)

4.3.2.2 What information was stored?

The project information stored in Team 3's *Google Docs* site and in their emails was examined. Team 3 stored a limited amount of project information. Each side of the team carried out its project tasks in half a day to a day and then handed over to the other side. See Appendix 4.3, Case 4, for data.

On Google Docs Web pages

Almost equal amounts of **Formal information content** (**53%**) and **Informal information** (**47%**) were found on the web pages, see Figure 4.26, (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 4, content on web pages.

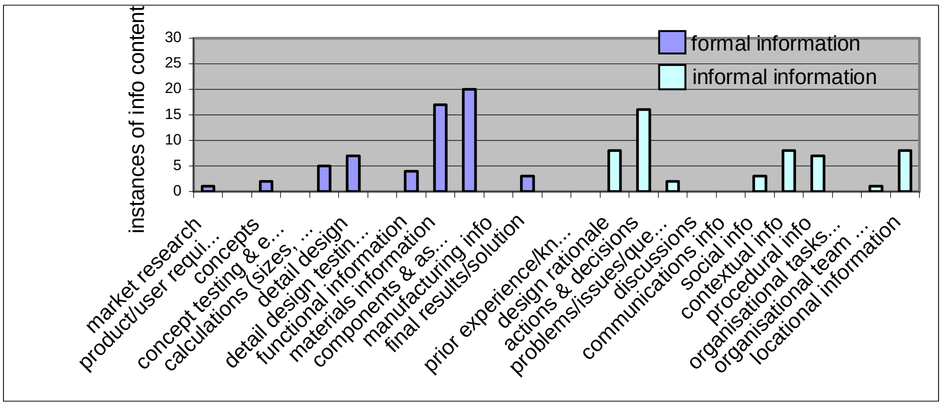


Figure 4.26: Instances of Information Content in Team 3 *Google Docs* Site

In Emails

93% of information content in emails was **Informal**, **7% Formal**, see Figure 4.27 (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 4, content in emails.

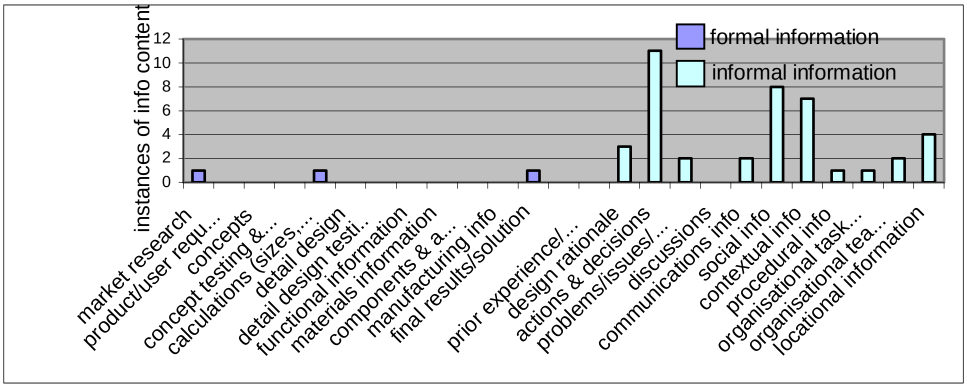


Figure 4.27: Instances of Information Content in Team 3 Emails

Amount of Information

Across *Google Docs* and emails Team 3 stored more **Informal information content (60%)** than **Formal (40%)**, see Figure 4.28. Due to other workload, Swinburne students were not able to contribute as much as they wished; contributing 32% of the information on the web pages compared to Strathclyde students' 68%. They did store a greater percentage of the instances of information content in the emails – 58%.

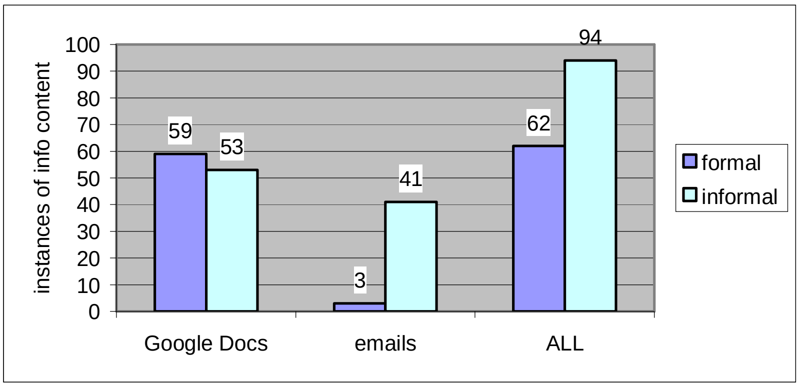


Figure 4.28: Team 3 Formal and Informal Info Content across Files, Wikis and Emails

Feedback and analysis regarding *what* information was stored revealed –

- Students had not realised they had stored as much informal information. (T3,v) They recognised that more informal information was needed than in collocated situations; to advise others and to keep a record of why certain things were done, since there was no opportunity to talk to distributed team members.

- Students noted that their global team tended to work as two sides. What they stored supported this, with each side storing only their selected/final outcome for their stage of the work, potentially losing information as a result. (3.2,v;r)
- Strathclyde students estimated approximately 60% of all project information had been stored in *Google Docs*. Not all research was stored; some early sketches were too 'sketchy' to store; and only one final concept was retained. Strathclyde students did not store all their concepts thinking that if they showed them to the Swinburne students their preferred option might not be developed. (3.1,3.2,v)

Information Carriers in Google Docs

Information on the *Google Docs* web pages was stored in four different information carriers – ***text* (65%)**; *photographs of models/objects/people* (21.5%); *photographs of scanned sketches* (7.25%); and, *as CAD drawings* (6.25%). See Figure 4.29. For more data on information carriers see Appendix 4.6.

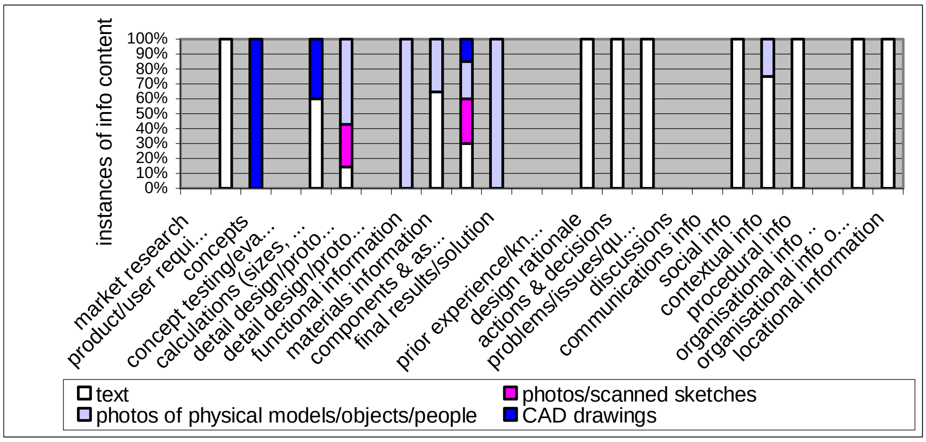


Figure 4.29: Instances of Information Content in Team 3 *Google Docs* by Information Carrier

Feedback and analysis regarding *information carriers* revealed -

- UK students confirmed text was their preferred medium for storing information. However they found it hard describing work and processes using words alone. (3.2,v:r)
- Students were positive about photographs. They conveyed design intent; showed how things worked; but often needed additional description or annotation. (3.1,v)
- Students photographed concepts to share and store. These often needed re-drawing for clarity which took additional time. (r)

4.3.2.3 When information was stored?

Local sides uploaded information to *Google Docs* for sharing only once, after their tasks were complete. Email contact was also limited. See Figure 4.30.

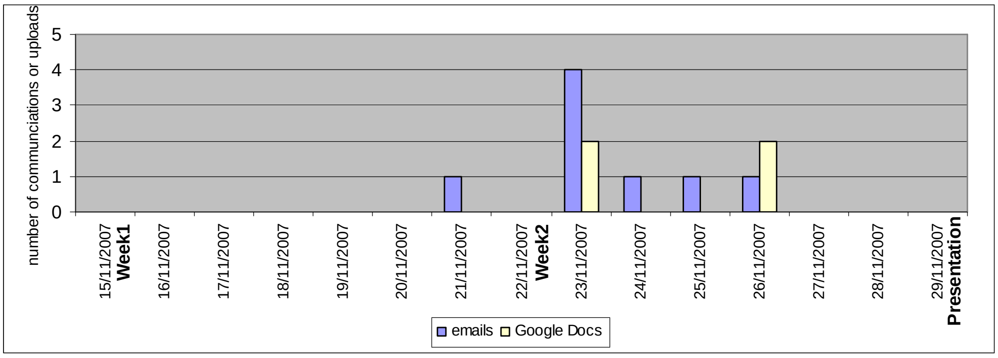


Figure 4.30: Team 3 - All Content Stored over Time

Feedback and analysis regarding *when* information was stored revealed –

- Information was not shared by local sides until completion of tasks, resulting in Team 3 not fully engaging with the distributed and collaborative experience. (T3,v)

4.3.2.4 How information was stored?

Feedback and analysis regarding *how* information was stored revealed –

- Students found it useful to describe processes in a step-by-step manner. (3.2,v)
- On reflection, Strathclyde students noted that information storing was rather ‘ad hoc’ and initially there were difficulties finding uploaded information. (3.2,v)
- Swinburne students noted no explicit rules had been created since the project brief gave guidelines on how to work. They followed the same format for storing information as the Strathclyde students (in a PPT slideshow created in *Google Docs*) which all students found easy to compile and view. (Swq;3.2,v;r)
- Strathclyde students, in hindsight, recognised the need to document information clearly and comprehensively, more so than in collocated situations. Greater explanation was required due to the lack of opportunity for discussion. (3.1,rr)

- The time available also impacted on the clarity of the work produced. Students reported, given more time, they would have produced more 2D & 3D CAD drawings which would have been more accurate than rough sketches. (r)
- Strathclyde students recognised the need for a PM during the project as a record of what happened. They found the stored information supported their reflective report writing – "*...kind of jog our memories a bit…*". (3.2,v)

4.3.2.5 Information valued by students

Nearly all information content types were '*greatly valued'* or given '*some value'* by all the students. Strathclyde and Swinburne students both placed greater value on the Formal information categories compared to Informal information categories. For greater detail see Appendix 4.7. The information Team 3 valued and what they stored differed. For example, both Strathclyde and Swinburne students '*greatly valued'* information on *concept testing* and *detail design testing* but neither side of Team 3 stored this category of information.

4.3.2.6 Summary of Findings from Study 2 Case 4

Several issues emerged from examining Case 4 –

- Insufficient time had been allowed to become familiar with the technology causing access issues and confusion over location of information early on.
- Students did not realise they had stored almost equal amounts of Formal and Informal information. They assumed Formal information would be greater. They also noted they were uncertain as to what constituted Informal information.
- Team 3 exhibited signs of ethnocentricity, working more as two sides and less as a global team.
- Text was used most to convey information but students found it hard to describe work and processes using text alone.

A summary of all findings from Case 4 can be found in a Mindmap in Appendix 4.11. All findings and issues will be discussed in greater detail in Chapter 5.

4.4 Study 3: Strathclyde/Malta

Study 3 examined the project information stored by two student distributed teams on the Global Design Project in November 2007, see Appendix 4.1 for details. Unlike the previous four case studies, this study took place in a synchronous context, with only an hour's time difference. Teams were assigned a tool to store project information and a VC tool for introductions and determining concept selection. No VC recordings were retained by teams. Students also used email communication.

Sampling

The same Strathclyde students from Study 2, Cases 3 and 4 formed new teams by partnering with 3 Maltese students per team. These teams constitute Case 5 & Case 6 and will be referred to as Malta Team 2 and Malta Team 3.

4.4.1 Case 5: Strathclyde/Malta Team 2

This team engaged well with the project and the information they stored was found to be well structured and organised. Students reported information was easy to find.

4.4.1.1 Where information was stored?

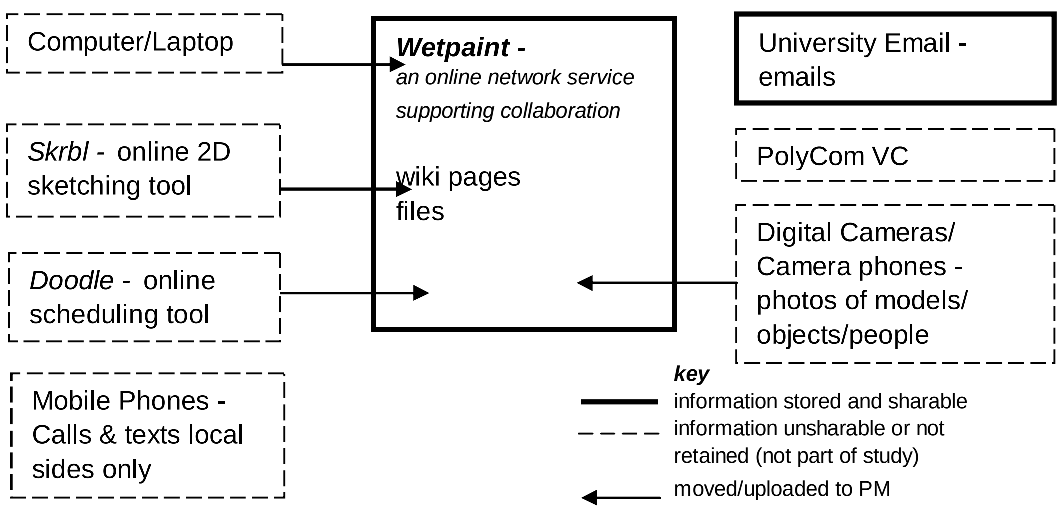


Figure 4.31: Malta Team 2 - Technologies Used and Information Studied

Malta Team 2 used *Wetpaint* and email to store and share project information. *PolyCom* VC was used to communicate and exchange information in real time. *Skrbl*, an online 2D sketch tool, was used to sketch project concepts. *Doodle*, an online scheduling tool, was used to plan and record availability and meeting times. All work created in *Skrbl* and *Doodle* was stored by embedding into *Wetpaint* wikis. Figure 4.31 shows all technologies used. Further detail can be found in Appendix 4.2, Case 5.

Feedback and analysis regarding *where* information was stored revealed -

- Students reported no issues with storing project information. *Wetpaint* was simple, easy and quick to use. Students were familiar with the web friendly nature of the environment. It also afforded good security. (2.1, 2.2,v; Mq)
- No paper was used. Drawings from *Skrbl* were embedded in *Wetpaint* wikis. These drawings, along with annotated text, recorded a real-time picture of the global team's thought processes but due to their simplicity they required to be used in conjunction with a communication tool. (2.1,2.2,rr) *Skrbl* sketches also helped the Maltese students overcome language barriers. (Mq)

4.4.1.2 What information was stored?

Project information in Malta Team 2's *Wetpaint* wikis and emails was examined. See Appendix 4.3, Case 5, for data.

On Wetpaint wikis

More instances of Informal Information content (**55%) were stored** than Formal information content on wikis, see Figure 4.32, (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 5, content in wikis.

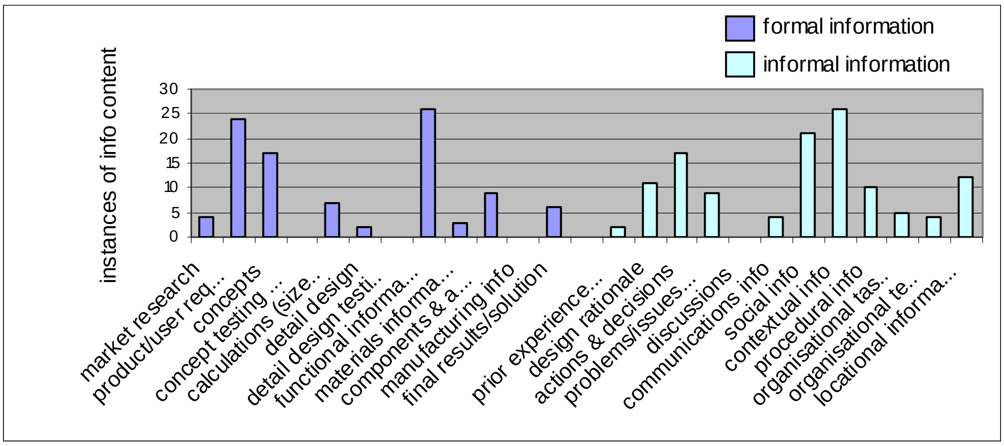


Figure 4.32: Instances of Information Content in Malta Team 2's *Wetpaint* Site

In Emails

100% of instances of information content in emails was **Informal**, see Figure 4.33, (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 5, content in emails.

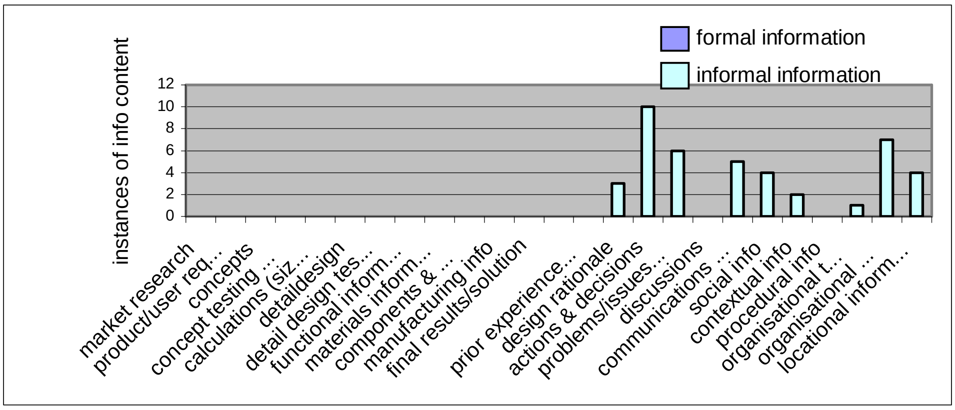


Figure 4.33: Instances of Information Content in Malta Team 2 Emails

Amount of Information

Overall, across wiki and email information content, **informal information content** was greatest (**62%**), see Figure 4.34. The Strathclyde-side stored 71.5% of the information content on wikis; the Maltese side, 21.5%; with 7% stored jointly (*Skrbl* sketches). Strathclyde students stored 71% of emails and Maltese students 29%.

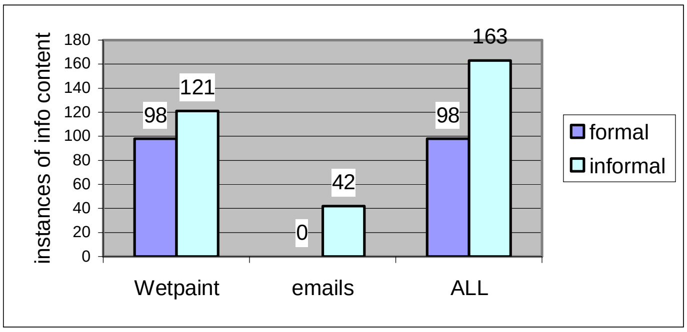


Figure 4.34: Malta Team 2 - Formal & Informal information across Wetpaint wikis & emails

Feedback and analysis regarding *what* information was stored revealed -

- Strathclyde students reported it was important to store *product/user requirements* and *functional information* for shared understanding. (2.2,v)
- Strathclyde students found it harder to share concepts distributedly and therefore shared less concepts when compared to collocated design. (MT2,v)
- Information from the joint brainstorming and concept generation stages was important to the Maltese students. (Mq)
- No VC recordings were retained by teams. Students noted they would not have referred back to the recordings due to the time it would have taken. (2.1,2.2,v)
- The high amount of Informal information stored was accredited to moving communications from email to *Wetpaint*; and to working more collaboratively with the Maltese students than with the Swinburne students. (2.1,2.2,v)
- Strathclyde students noted a lot of informal project information was lost by not storing *PolyCom* sessions– e.g. *design rationale, actions & decisions* and *contextual information.* Overall only about 50% of the overall project information had been stored; see Appendix 4.5. (2.1,2.2,v)
- Strathclyde students were sometimes uncertain as what had been stored. For example, they reported no *actions & decisions* had been stored due to VC. (MT2,v) However, examination of *Wetpaint* evidenced high numbers of instances of *actions & decisions* on project processes, activities and concept decisions.
- Students recognised the importance of storing project information as integral to how they worked - “*...part and parcel of what we do as product design engineers”*. (2.1,v)

Information Carriers (Wetpaint)

Instances of information content were richest as **text (81%)**; then *CAD drawings* (14%); *photographs of physical models/objects/people* (3.5%), and as *spreadsheets* (1.5%). For more data on information carriers see Appendix 4.6. See Figure 4.6 for the different information content categories stored.

Feedback and analysis regarding *information carriers* revealed -

- Students found 2D CAD sketches easy to store and useful in terms of progressing the project in real-time, even though *Skrbl* functionality was fairly basic. (2.1,v)

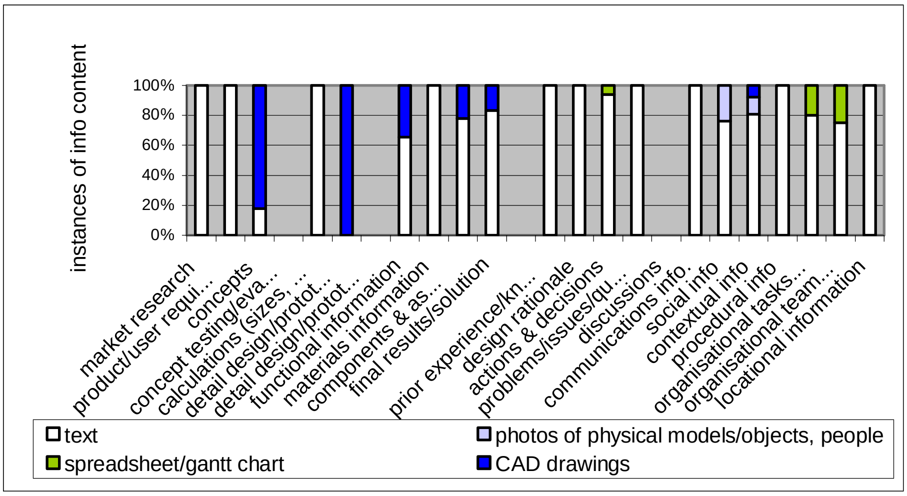


Figure 4.35: Instances of Information Content in Malta Team 2 *Wetpaint* site by Information Carrier

4.4.1.3 When information was stored?

Examination of *Wetpaint* and emails evidenced Malta Team 2 completing work in the first week of the project. Information storing to *Wetpaint* and email use was frequent during this week (see Figure 4.36), with students storing research material and generating concepts prior to a virtual f2f design session, conducted via *PolyCom*.

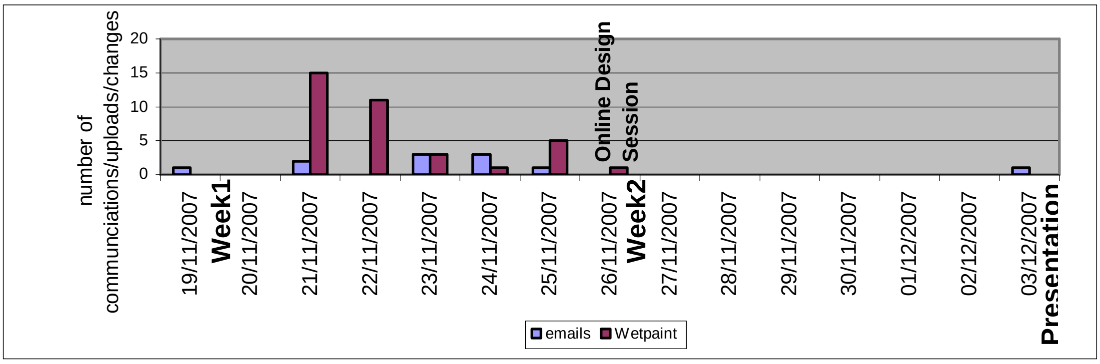


Figure 4.36: Malta Team 2 *Wetpaint* Activity and Email s over Time

4.4.1.4 How information was stored?

Feedback and analysis regarding *how* information was stored revealed –

- The students in Malta Team 2 reported few information storing issues. (MT2,v)

- Students experienced that working in a distributed context required additional effort to make information clear and comprehensive. A few times information was not sufficiently clear due to *Skrbl's* basic output. (MT2,r)
- No joint rules were explicitly created by the team, but the experience gained from the first distributed project by the Strathclyde students helped organise and structure the team information. The Strathclyde-side set up the *Wetpaint* site and all students were advised of where information should be stored. (2.2,v)
- Students recognised the need for an online centralised store, a PM, for distributed design project work. When asked at interview if a distributed project could have been done without storing information – they confirmed *"no"*. (MT2,v)

4.4.1.5 Information Valued by Students

The value Strathclyde students gave to the different information content categories has been reported in Section *4.3.1.5*. Maltese students *'greatly valued' calculations, functional information* and *materials information* due to their mechanical engineering background. (Mq) The Maltese-side did not value *social information, communications information* or *organisational information on tasks* or *team* since the Strathclyde-side was managing the project. See Appendix 4.7 for more detail.

4.4.1.6 Summary of Findings from Study 3: Case 5

Malta Team 2 experienced few information storing issues. Case 5 emerging issues are summarised below –

- Prior experience of information storing in a distributed context helped the Strathclyde students to organise and structure the team's distributed information.
- Students experienced the difficulties of sharing concepts during distributed design. They reported it was harder than collocated design due to reduced opportunities for communication; misunderstanding of information; and the time taken to ensure clarity and comprehension.
- Students found that distributed working required additional effort to make information clear and understandable.
- The VC sessions helped foster a greater collaborative experience during the project. However, meeting via VC resulted in an overall lower percentage of information content being stored by the team.

- A comprehensive PM would have been achieved if VC sessions had been recorded and stored. Students noted however, they would not refer back to VC recordings. High instances of informal information were lost as a result.
- Even when designing synchronously, students used text most often to store project information. Instances of both Formal and Informal information content occurred most often as text.

A summary of all findings from Case 5, in relation to the research questions and clustering, can be found in a Mindmap, in Appendix 4.12 and will be discussed in greater depth in Chapter 5.

4.4.2 Case 6: Strathclyde/Malta Team 3

Malta Team 3's information storing issues were fairly limited. See Appendix 4.1 for case study context details.

4.4.2.1 Where information was stored?

Malta Team 3's project information was stored in files on *Google Groups* and in emails. Figure 4.37 shows all technologies used by Malta Team 3. Further detail can be found in Appendix 4.2, case 6.

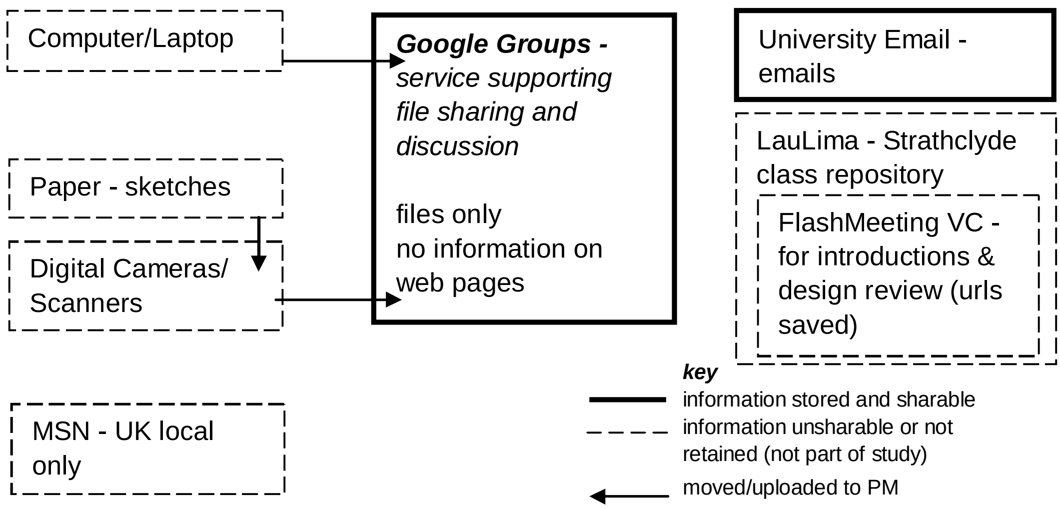


Figure 4.37: Technologies Used and Information Stored by Malta Team 3

Feedback and analysis regarding *where* information was stored revealed -

- Initially each side of the global team could not find information. There was confusion between *Google Docs* and *Google Groups*, with Strathclyde using *Google Docs* and Malta using *Google Groups*. The team resolved to use *Google Groups* (via email). (3.1,v)
- *Google Groups* was found to be successful for storing information since students were familiar with its functionality before the project started and it could be accessed by all at any time. (r;Mq)
- Malta Team 3 relied heavily on the *FlashMeeting* desktop VC system to 'meet' f2f and work synchronously, conducting five sessions (when only two were required). The VC sessions' urls were saved to the Strathclyde class repository but were inaccessible by the Maltese-side. Examination of VC information content was found to be mainly informal but this was lost to the team's Project Memory, since it was not able to be shared. (3.2,v)
- Students used desktop 'chat' to exchange project information due to *FlashMeeting's* low quality video and sound and background noise. Students found it difficult to explain concept designs using text. (rr)
- Using information stored in *Google Groups* during VC sessions proved effective; helping with Maltese language barriers. (r;rr;Mq)

4.4.2.2 What information was stored?

Malta Team 3 only stored project information in files, uploaded to *Google Docs*. See Appendix 4.3, Case 6, for detail. The files were dense with information and included text, images and annotated sketches.

In Files in Google Groups

More instances of **Formal information content (64%)** was stored than **Informal (36%)** in the files, see Figure 4.38 (Appendix 4.3 for instances). For more detail on the top five information content types stored, see Appendix 4.4, Case 6, content in web pages.

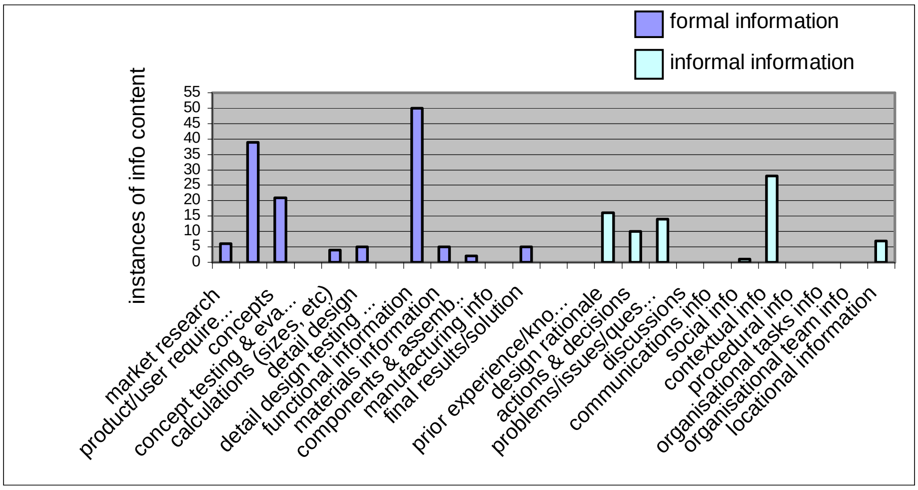


Figure 4.38: Instances of Information Content in Malta Team 3 *Google Groups* Site

In Emails

100% of instances of information were **Informal in email**, see Figure 4.39. For top five information content types stored, see Appendix 4.4, Case 6, content in emails.

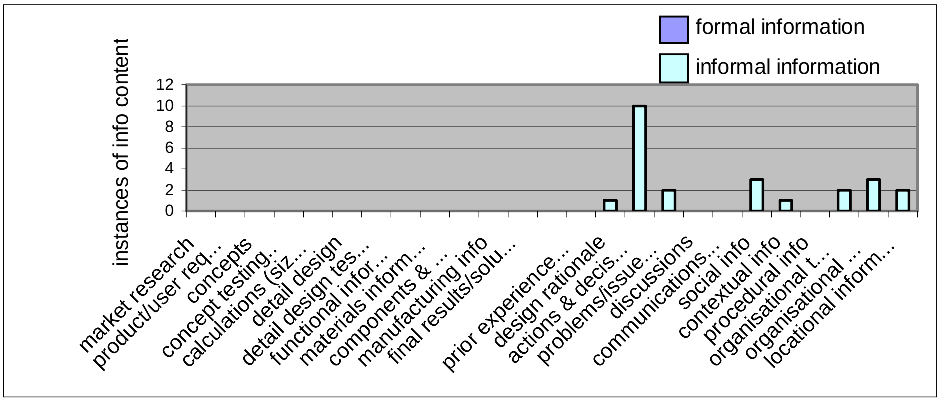


Figure 4.39: Instances of Information Content in Malta Team 3 Emails

Amount of Information

Across *Google Docs* and email, Malta Team 3 stored **more instances of Formal information** (**58%**) than **Informal** (**42%**), see Figure 4.40. Overall, the Strathclyde-side stored 64% of the instances of information content in the files more than the Maltese-side, 36%. They also contributed more information instances to email (75%).

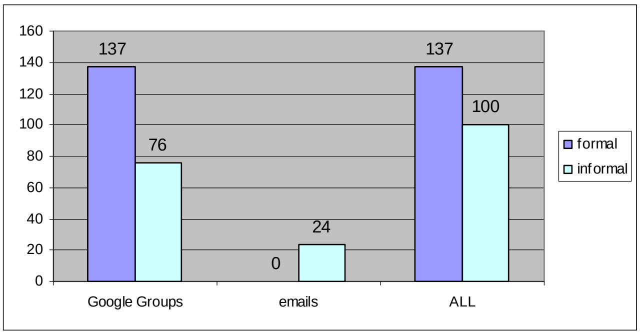


Figure 4.40: Malta Team 3 - Formal & Informal information across *Google Groups* & Emails

Feedback and analysis regarding *what* information was stored revealed -

- Since the project brief did not require formal testing, no *concept* or *detailed design testing* was stored. No information was retained on *prior knowledge, discussions, communications information, procedural information, organisational information on tasks* or *on team*. Students attributed this to their use of VC and email to discuss how project work could be carried out. (MT3,v)
- Students had summarised project work and processes and as such information was more factual, less rich and contained less rationale. Annotated sketches contained valuable informal information. (r)
- At interview the Strathclyde students felt a fairly complete record had been kept. (3.1,v) If the *FlashMeeting* conferences had been included, they estimated between 80-90% of project information had been stored. (3.1,3.2,v)

Information Carriers (in files)

The information content in the files in *Google Groups* was captured in three different information carriers – ***text* (68%)**, *photographed or scanned sketches* (21%), and *images from the internet* (10%). For more data on information carriers see Appendix 4.6. See Figure 4.41 for the different information content stored in files.

Feedback and analysis regarding *information carriers* revealed -

- Students found annotated hand-drawn sketches to be a good method to convey concepts with sufficient clarity. (r)

- Stored photographs of *market research* and *user requirements* sourced from the internet were often referred back to when generating sketch concepts. (MT3,v)

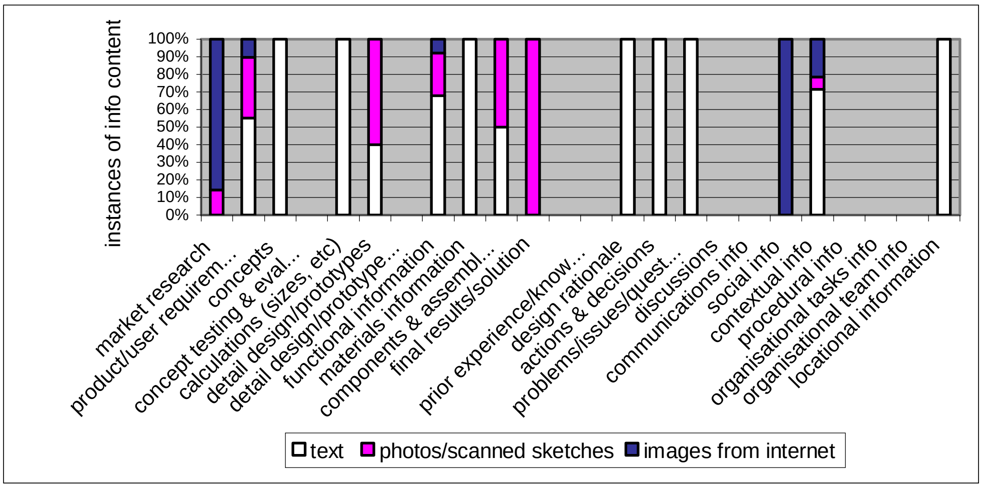


Figure 4.41: Instances of Information Content in Malta Team 3 Files by Information Carrier

4.4.2.3 When information was stored?

Dates for file uploads, emails and *FlashMeeting* sessions evidenced that Malta Team 3 worked in their local sides for most of the first week, uploading only occasionally. In Week 2 information storing was more collaborative and frequent, see Figure 4.42.

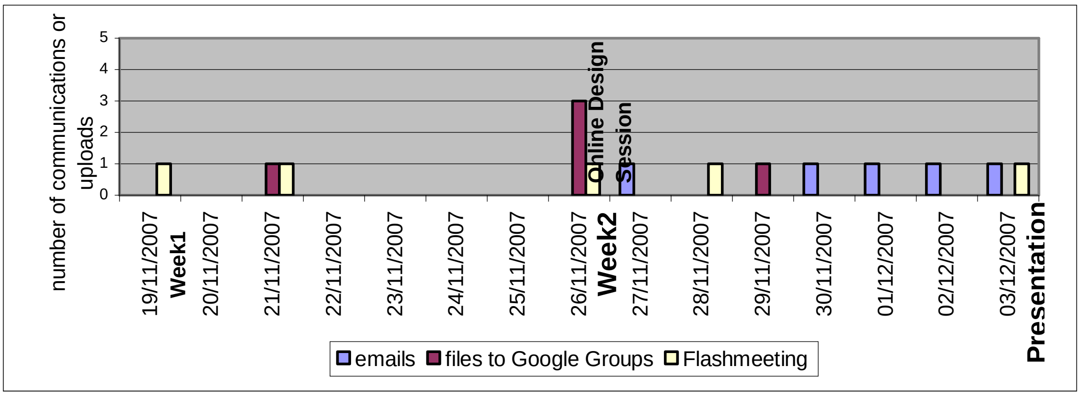


Figure 4.42: Malta Team 3 All Content Stored over Time

4.4.2.4 How information was stored?

Feedback and analysis regarding *how* information was stored revealed -

- Students in Malta Team 3 did not establish any rules or strategies for storing information. They used email to solve any problems as they arose. In hindsight they realised it would have been beneficial to have spent time as a team thinking about the tools to be used, appropriate to the project tasks. (3.2,v;r)
- Information was stored for the purpose of discussions at VC sessions. (Mq)
- Information in the files was fairly detailed. The students recognised that in distributed design work information needs to be self-explanatory and recorded clearly for distributed partners to understand, otherwise time is wasted. (3.2,v)
- Students noted that, compared to collocated design, information was harder to convey understandably in distributed design. (r)
- Students found technologies had a significant impact on how information flowed and how design activities were carried out. Ideas were difficult to convey asynchronously and students often reverted to f2f VC to progress work or clarify project details. (3.2,rr)
- The students realised that project work required an information storing area. Without it, it would have been difficult and would have slowed project progress. (3.2,v)

4.4.2.5 Information valued by students

Both Strathclyde and Malta *'greatly valued' product/user requirements, concepts, the final results/solution, problems/issues/questions, communications information* and *procedural information*. (UKq;Mq) Maltese students also *'greatly valued' actions & decisions* and *locational information,* which helped them find project information. (UKq;Mq) The Maltese students valued Formal information more than Informal information. (Mq)

Strathclyde students valued all information content categories except for *discussions* which seemed to contradict project activities, with the team spending considerable project time in discussion in VCs.

4.4.2.6 Summary of Findings from Study 3: Case 6

Malta Team 3 had few information storing issues. When they did have problems they resorted to email and VC for resolution. Emerging findings and issues were as follows for Case 6 –

- Most of the issues Malta Team 3 had were with the VC technologies rather than information storing technologies. Students reported that a combination of VC and using stored information in 'real time' worked best.
- More instances of Formal information content were stored, for two reasons: firstly project information was summarised which tended to lose the informal information and also, informal information was lost due to not retaining VC sessions.
- On reflection students wished they had spent more time prior to the start of the project thinking about how to store their information using *Google Groups* to greater effect.
- Students found it harder to convey information in distributed design; realising that information had to be clearer and more comprehensive than in collocated design.
- *Locational information* in emails was useful in directing students to project information in files.

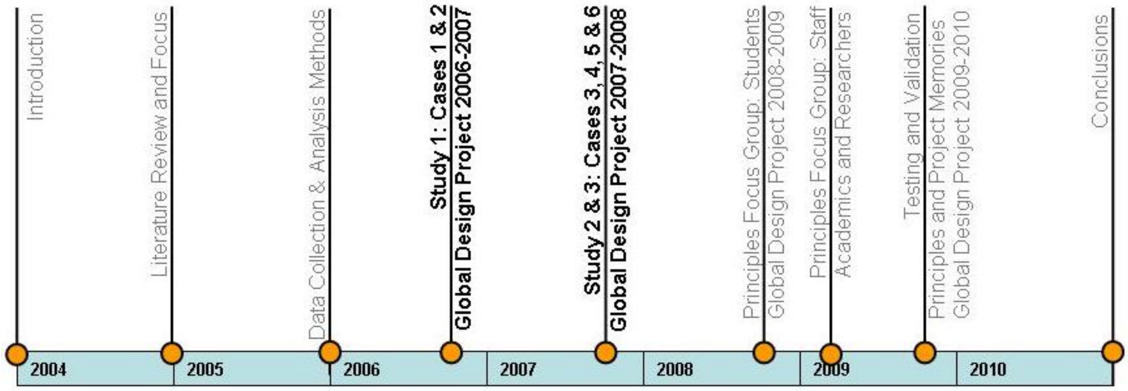
A summary of all findings from Case 6 can be found in a Mindmap, in Appendix 4.13 and will be discussed in greater depth in Chapter 5.

4.5 Summary

Chapter 4 has presented the information storing findings and issues experienced by six distributed student teams in the context of a Global Design Project. 31 students from Strathclyde, Swinburne and Malta Universities contributed to Questionnaires, and Semi-structured interviews, validating the analysis of the information content stored in their online project sites. The studies evidenced many varied issues. These included, information stored in several places; information often being ad hoc and lacking in organisation or structure. There was a lack of planning, strategy or rule creation before project work began. Information was lost at times or could not be found easily. Stored information often lacked rationale which resulted in an incomplete and fragmented ‘picture’ of the design development. Unfamiliarity with tools also caused problems, as did inconsistent storing of project information. Students found the storing of Informal information beneficial but it was time consuming and they were sometimes uncertain as to how much to store.

It was evident that engineering design students had many issues with distributed team-based information storing and that this had an impact on their experience of global design project work. These issues are now discussed in greater detail in Chapter 5.

5 Issues, Discussion and Implications from the Studies



5.1 Introduction

Chapter 4 presented and summarised the findings and issues for each Case Study in terms of what information was stored, where, when and how. This Chapter will now focus on discussing the issues and implications of these findings; justifying the need for a set of guiding *Principles for d-DIS* and a Project Memory. The emerging issues are presented under the following categories –

- *Information Systems – where?* : issues related to the technologies used;
- *Information Stored – what?* : issues related to the type and amount of information stored by teams, information carriers, etc.
- *Information Patterns – when?* : issues relating to emerging storing patterns;
- *Information Strategy – how? and why?*: issues relating to a lack of an information storing strategy and how the students stored information.

A series of Recommendations are then drawn from the emerging issues at the end of the Chapter, see Table 5.3 (pages 139-142), which inform the development of the set of guiding *Principles for d-DIS* and the PM criteria.

5.2 Information Storing Systems – *where*?

5.2.1 The Need for a Centralised Information Storing Tool

Research in networked learning has shown that groupware technology can support collaborative learning through the creation of a shared information workspace (Shaikh & Macauley, 2001; Sikkel et al., 2002). Nicol and McLeod (2004) show that the creation of task relevant documents supports design and project learning in an engineering design course. Students in the Studies in this work, recognised the need for a centralised information store to support the management of their distributed information. For example, students in Case 4 reported a good information storing experience and that access to centralised information made decision-making easier. However, this was not so for all Cases. Overall students' information management skills were found to vary and at times to be lacking. In Case 2, students had a poor information storing experience; finding that using too many systems (*LauLima, Socialtext* and email) meant information was fragmented and duplicated. They became frustrated and communication weakened as a result.

Students were aware of the high importance placed on the retaining of information in industry and recognised the need to store project information in practice –

> *"Information was stored because it was part and parcel of what we do as product engineers."* (2.1,v)

Recommendation drawn –

- **Recommendation for centralised information storage in distributed design team work.**

5.2.2 Selection of Technologies

The selection of technologies for information storing should be based on a consideration of the requirements for the project and tasks; the people involved and the time duration. All members of the global team should contribute to this consideration equally in order to be most effective. It can of course be argued that it is difficult, especially for students, to determine what these requirements might be, prior to starting a project. But having experienced a Global Design Project, students were able to identify general requirements for these tools. For example, during Case Study 2's UK reflective session students listed a number of requirements - *"everyone could see information regardless of location"; "allowed access 24/7"; "simple and easy to use"; "good navigation"; "only requires a browser"; "no file format issues"; "no file limit size"* and *"offered instant messaging alongside information storing."* (T6UK,r) There was also a desire for flexibility. At The Principles Focus Groups students expressed concern at being tied into technologies at the beginning of a project and preferred to adopt a framework which afforded adaptability with the introduction of new (and integrated) technologies as and when required.

Subrahmanian & Jellum (1998) note that shared workspaces, by themselves, may not be sufficient to meet the support needs of certain collaborating groups. Students found this to be the case. The use of a communications tool with their information storing tool was especially beneficial. Analysis of emails showed that communication technologies which stored high percentages of Informal information content added context to stored formal documents. Most students used email; however, one team (Case 3) used integrated 'chat' in *SocialText* to greater benefit, keeping all communications and information storing in one centralised place. The opposite also held true - students in Study 3 (using VC) noted that communication tools alone would not have been sufficient. They noted that without an information storing tool –

> *"…it* [the project] *would have been difficult and would have slowed things down. Better to have a storage area."* (M3.2,v)

Recommendations drawn –

- **Recommendation for tools to satisfy distributed information storing needs, including adaptability.**
- **Recommendation for a communications tool to support information storing tool.**

Students were in unanimous agreement that any technology used should not impede the design process. Tools must have an acceptable learning curve; be simple and quick to use; and have a simple interface. See Appendix 4.1 for technologies used by teams. In Study 1, the system used by the teams, *LauLima,* proved too complex for the short distributed projects since the global partners were unfamiliar with it. Uploading took too long; global partners had insufficient training in its use prior to the start of the project causing inequality in skill levels and unequal contributions. Consequently simpler tools were used in subsequent classes. Students used *Socialtext, Google Groups, Google Docs* and *Wetpaint* to store project information. Fewer issues were reported relating to these technologies: information could be stored and uploaded easily; information could be found quickly and less time was lost as a result. Less frustration and greater satisfaction was generally expressed.

Using these systems however, students needed to be made aware of the issues surrounding security of project information. Whilst username and password-secured, such systems would not be considered in industry to be robust or safe enough for confidential or sensitive project information.

Recommendation drawn –

- **Recommendation for selected tool(s) to be simple to use so as not to interfere with the design process.**

5.2.3 Familiarisation with Tools

Lack of training time and unfamiliarity with the tools before the start of some Global Projects caused confusion and delayed the start of product development. Teams noted that being familiar with the technology before the start of the project made use of the tool easier. This seems obvious. However, more than 50% of the teams started project work without sufficient knowledge of the tools they were using.

In Study 1, unequal systems' competencies across the sides of distributed teams led to a lack of engagement to an extent by those unfamiliar with the information storing tools. UK students were familiar with the *LauLima* system; their global partners were not. Teams resorted to using systems they were more familiar with, e.g. email; or in Case 2, the USA students used another shared workspace, *Socialtext*, duplicating information and effort. In Study 3, Case 5, limited use and unfamiliarity with the *PolyCom* system meant that students did not know how to save conversations or VC meetings, resulting in a loss of information, mainly Informal information.

In Studies 2 and 3, technology-related information storing issues tended to be in relation to registering and the initial accessing of stored information. Students in Case 3 lost two working days due to difficulties with the acceptance of new members to their shared online sites. They reported the systems were easy to use once these early issues were overcome and they became familiar with the basics of the systems. Students reported a preference for simple wiki-based systems as they were already familiar with the nature of web-based systems. Few other issues were reported on the use of the technologies.

Recommendation drawn –

- **Recommendation for all global students to be familiar with the tools prior to the start of the project.**

5.2.4 Longevity of Information

Stored information has a life duration dependent on its context, situation or need. Previous work of the author defines a *Project Memory* as –

> *'…a collection of formal and informal information and knowledge, useful both to team members working actively during a project and thereafter as a record of activities, project history, and results.'*
>
> (Grierson et al., 2006, p.398)

In an educational context, online project information stored throughout a project helps students achieve a shared understanding of the project problem; it helps support decision-making and project progress. It also affords great educational value both during and beyond the project life in terms of student reflection. As part of class assessment, UK students were required to write reflective reports on their experiences, referring back to the information they had stored during the project as source material. Two teams were disadvantaged. Students in Case 3 unwittingly used a time-limited trial version of *Socialtext* which expired before they started to write their reports. Students in Case 2 were disadvantaged to a lesser extent. They were unable to access videos in *YouTube*, linked from *LauLima*, which contained *social information* on global partners. These had been removed immediately following the completion of the Global Design Project and the links were no longer 'active'; a problem often associated also with links to external web sites.

The information stored by students in their *Project Memories* has additional educational value in terms of staff re-use of material as good exemplars for use in future Global Design Classes and also for external assessment and for research purposes.

Recommendation drawn –

- **Recommendation for selected tool(s) to retain information and for it to be accessible for the duration of the distributed project, and beyond for academic purposes (e.g. student reflection, staff re-use, external assessment and research).**

5.2.5 Awareness of Information Location

One of the most frustrating aspects of distributed information storing for the students was the time lost trying to locate information. Students felt this time would be much better spent designing. Teams in Studies 1 and 2 experienced and reported some level of difficulty in terms of being able to find shared project information, particularly early on in the projects. They found it confusing having several ways or places to store information in some of the systems. Most teams reported that initially it was not obvious where information was stored. This however was not unexpected as only one team had discussed where information was to be stored at the outset of their Global Design Project. In Case 6, the distributed sides of Team 3 even started using different systems. The UK students set up *Google Groups* for the storing and sharing of project information. Their Maltese partners thought information was being stored on *Google Docs* and for several days they could not find each others' stored project information.

As projects developed students used email or communications tools to notify global team members of newly uploaded or added information and of its location. All students in a distributed team need to know or be aware of where project information is stored in order to achieve quick and successful retrieval and reduce confusion and frustration.

Recommendation drawn –

- **Recommendation for all global students to be able to find information easily and quickly.**

5.2.6 Implications for Information Systems

The Studies have shown that a lack of familiarisation with the use of the technologies and an understanding of the tools to meet information storing needs before a project, resulted in several teams not finding information quickly and easily, early on. This further compounded frustration; reduced team cohesion and impacted negatively on project progress and product outcomes for a few of the distributed teams. All students need to be familiar with the systems and know their general functionality and capabilities before the start of a distributed project, in order to make the best use of them otherwise further time will be lost. Time has to be factored into the design of any global project for preparation (Gibson & Cohen, 2003).

In instances of poor, or no communication, students tended to turn to the technologies they were most familiar with or used most often, for example, mobile phones or email. This has implications for information storing. Crucial information can be lost as students do not store phone conversations and whilst email has been shown to contain valuable Informal information students do not naturally retain this as part of their PM.

Systems or tools need to be integrated. A unified central store, or PM, proved more suitable than information stored in several places. Systems require to be secure and retain information for as long as necessary - for use as exemplars, student reflection, staff re-use; external assessment, research etc. Due to the indeterminate and unpredictable nature of the design process it is often difficult to anticipate all information storing requirements prior to a project start. Allowances should be made for the adaptability or introduction of new tools (linked or embedded for effectiveness) to accommodate any new information storing needs as project work develops.

5.3 Information Storing – *what*?

5.3.1 Amount of Information

The amount of information stored on each project varied. Many factors affected this – available time, team members, project requirements, etc. and as such it is difficult to compare across the cases. However, what was evident was that not all project information collected and generated, was stored, see Appendix 4.5 for amounts of information content stored by each team. Study 1 is covered in greater detail.

On the asynchronous projects UK students reported that between 50-70% of information was stored. Time impacted upon the amount of information which could be stored. The opportunity to discuss work via VCs, also affected the amount of information stored. On synchronous projects UK students noted this reduced to about 45-50%; with less informal information stored. Students reported the more they communicated f2f (via VC) the less overall project information they stored.

One of the aims of storing and recording project information is to capture a comprehensive and rich picture of the product, project and its processes. Lack of recording of Informal information on student design projects can create an incomplete picture of work on a project. In some cases – sketches lacked rationale; changes needed explaining; decisions needed clarifying, etc. Verification caused delays. Traditionally students focus on the last aspect. In distributed design work it is necessary to store all elements for richness and better understanding. ‘Richness’ is not a new concept. It reduces misunderstanding and plays an important part in an organisation's success –

> *"Organisational success is based on the organisation's ability to process information of appropriate richness to reduce uncertainty and clarify ambiguity".* (Daft & Lengel, 1984, p.194)

The extent of how well the information storing records a comprehensive picture is determinant on a number of factors –

- the type of information content and information carriers (wide range);
- the level of information captured (detailed and meaningful);
- captured or linked context (relationship with other information); and
- structuring of information (for easy retrieval).

With the exponential increase in available information, students need to be able to evaluate and assess sourced and generated information and reduce the amount of appropriate information to be stored, i.e. to 'filter' and reduce the information. Students reported they find this hard to do. For example in Case 1, Team 5 felt everything had to be recorded –

> *"…even tiny bits which may appear irrelevant as they may become important later."* (UK,q4)

Not all teams had this view, recognising that storing too much information was also problematic – *"…counterproductive to store everything as it takes time and effort."* (2.1,v) Too much information contributed to a loss of focus; storing of unnecessary information wasted time; and information was often not re-visited if it was lengthy. Managing information includes the disposal of information; it is not about storing everything found and generated. A general Principle of Design, elevated to one of the two Axioms of Design by Suh, is that information should be kept to a minimum (Suh, 1990). However, information 'under load' should also be avoided as this can severely affect decision-making and product outcomes. Students find it difficult to get the balance right. Often this comes with experience. Recommendations drawn from above –

- **Recommendation to store and record a comprehensive 'picture' of project problems, processes, rationale and outcomes.**

- **Recommendation that not all information needs to be stored; avoid information 'overload'.**
- **Recommendation to avoid information 'under load'.**

Reflection on the Global Design Projects constituted 50% of the UK students' assessment. (Distributed partners were not assessed.) This impacted on the amount of information produced and stored by the sides of teams. Assessment led UK-sides to store more information than their global partners, see Table 5.1.

What: Contribution of information instances by local sides	Study 1						Study 2				Study 3			
	Case 1			Case 2			Case 3		Case 4		Case 5		Case 6	
	files	wikis	email	files	wikis	email	sites	email	sites	email	sites	email	sites	email
UK %	52	74	35	98	68	69	54	80	68	42	71.5	71	64	75
Global Partner %	48	26	65	2	32	31	46	20	32	58	21.5	29	36	25

Table 5.1: Amounts of Information Content Stored across Cases

Indeed in Studies 1 and 3, UK students reported an element of frustration that their global partners had not contributed as much information. Students regarded equal contribution to storing in distributed projects as equal engagement.

Recommendations drawn from above –

- **Recommendation to contribute equally across distributed sides of a team to avoid inequality and frustration.**

Amount of Formal and Informal Information Content

Traditionally students share and retain the more formal documentation from project work, e.g. the selected *concepts* and *final results/solutions* rather than information on the process towards the final solutions. The more Informal information content categories (e.g. *design rationale, decisions* and *organisational information*) are seldom recorded and retained during student design projects, but have high value in terms of student learning. This reflects current practice in design education - more product-focused than practice-focused.

Quantification of the instances of the Formal and Informal information content stored by the students in Cases 1-4 (asynchronous distributed work with no real-time communication) showed that most teams stored approximately equal amounts of Formal and Informal information (or as in Case 4, much more Informal information). See Appendix 4.3 for detail. This was unexpected and surprised the students. They felt that more Formal information had been stored since they had focused on producing solutions. In Study 1, more Formal information content instances were stored in files. A greater number of instances of Informal information content were stored on wiki pages and in emails.

Greater evidence of Formal information content storing was expected on synchronous projects due to the loss of Informal information through f2f exchange and discussion opportunities. This was the case with Team 3 in Case 6. They stored more Formal information content on project outputs at each stage; discussing but not recording as much of the Informal information. They also chose to store information content in files rather than on web pages which in itself contributed to lower amounts of Informal information. As shown in Study 1, files contained greater instances of Formal information content. However, Case 5 showed the opposite. This team stored a high number of instances of Informal information which they credited to a greater collaboration with the Maltese students through socialisation, afforded by VC. They felt more connected and as a result stored more Informal information. So, it is inconclusive to report that synchronous project work results in less Informal information content, due to the opportunities for meeting f2f, as might be expected, however the findings do corroborate the premise that socialising increases collaboration and informal communication is a driver for successful teamwork (Hinds & Mortensen, 2005).

Recommendations drawn –

- **Recommendation that at least half of information stored is informal to add context and meaning to formal documents.**
- **Recommendation to store more Informal information when working more asynchronously.**

5.3.2 Information Content – Formal and Informal

Formal information content

The greatest instances of Formal information content stored by the distributed teams in their online project sites were on the product itself –

- *functional information* (in top 3 of 5 of the cases);
- *materials information* (in top 3 of 4 of the cases);
- *product/user requirements* and *concepts* (in top 3 of 3 of the cases); and,
- *components & assembly* and *detailed design/prototype* (in top 3 of 2 of the cases).

In all Cases 1-4, where a prototype was a project requirement, *functional* and *materials information* were in their top 3 of most stored instances of formal information content. Students reported that in the context of the Global Design Project, storing these types of information content was important to inform others of how concepts and prototypes were intended to work and precisely what they should be made from. They noted that storing and sharing *product/user requirements* helped them develop a shared understanding of the project problem and afforded a key set of requirements that everyone could work to.

Most sides of teams developed a number of concepts (between three and seven) as *photographed or scanned sketches* with annotated descriptive notes and rationale, and stored and shared these with their distributed partners. They chose not to store very early sketches of concepts which in their terms were “worthless”. In Case 4, UK students chose to store only one concept disregarding rough concepts and any of their less preferred options. They considered that, had they stored all their final concepts, a less preferred one might have been selected by their distributed partners. Need for one side to remain in control of the process indicated a lack of trust and collaboration. This shows that the information stored by teams in distributed design project work, or not stored in this case, can affect the project outcome and final solution.

Most teams were task-focused, possibly due to the short duration of the projects. There was a tendency to store only information which students felt relevant specifically to the project, therefore no *manufacturing information* and very few *calculations.*

Informal information content

The greatest instances of Informal information content stored by the distributed teams in their *Project Memories* were –

- *contextual information* (in top 3 of 5 of the cases);
- *design rationale* (in top 3 of 4 of the cases);
- *actions & decisions* (in top 3 of 3 of the cases);
- *locational information* (in top 3 of 2 of the cases); and,
- *social information, communications information, procedural information ; problems/issues/questions* and *organisational information on tasks* and *on team* (in top 3 of 1 of the cases).

Students were less familiar with the term Informal information. For example, several students didn't know what *contextual information* was and the value it could add. Despite this it appeared in the top 3 of five of the cases. By trying to make information as explicit as possible for a better understanding in a distributed context, students had stored high percentages of *contextual information* without realising. Issues often resulted as a lack of context. For example, in Study 2, the Swinburne students didn't inform their distributed partners that their final degree examinations were the week following the Global Design Project and as such they could not contribute as much as they had wished.

Informal information is time consuming to store. Students were more likely to store the formal project documentation than the Informal information if time were a factor. However this creates a conflict. In a distributed context there is greater need for and reliance on Informal information to make sense of the more Formal documentation. A high number of instances of Informal information content were found in email communication and on wikis. There is the potential for the creation of links and relationships between Informal information and the more Formal project information and documentation without too much additional time and effort. Shared workspaces are a framework within which to do this but students need to make the relationships much more explicit; for example through the hyperlinking of wiki pages and signposting of information. Additional time should be built into projects to allow for this. Emphasis should be placed on the storing of Informal information by academics in global project work and the mechanisms used to convey it. A lot of Informal information was successfully stored in meeting minutes e.g. *design rationale*, for sharing with the team; looking back for assessment and moving the project from stage to stage; *actions & decisions* for accountability; and key *problems/issues/questions*. Students recognised that more Informal information had to be stored when working distributedly in order to inform the other side of the team - *"Needed to explain more when in an asynchronous situation."* (3.2,v) This was additional to collocated design. Distributed partners appreciated receiving not only the design work and changes from distributed partners but more beneficially the rationale for the design changes. Increasingly students are being advised to include rationale and justification in reports and deliverables for academic assessment purposes. Students also noted that *organisational information on the team* and *tasks* were useful to store and share to keep everyone aware. It should be noted though that most of this information content was stored during the project and not at the beginning, reinforcing the fact that teams had not adopted a project strategy early on but had rather allowed information storing to evolve or happen.

Recommendations drawn –

- **Recommendation that Formal information is stored on the product.**
- **Recommendation that Informal information is stored on product, process and people in order to support development during the project and add meaning to the Formal documents**.

5.3.3 Information Carriers

Design is a unique type of problem solving. It requires the generation of external representations of its states and paths (Restrepo et al., 2000). The wide range of information carriers used across the teams to externalise and thereby store and share distributed information were – *text; photographs of physical models/objects/people; photographs or scanned sketches and notes; 2D CAD drawings; images from the internet; spreadsheets;* and *video*. Studies to date point to a 'richness' due to a variety of media and modes of exchange across all design dimensions (Hales, 1987; Tang, 1989; Ullman, 1987; Clark & Fujimoto, 1991; Leifer, 1991). The key to selection for each team was time – whichever methods proved quickest dependent on the skills and knowledge of the global team members. In Studies 2 and 3 a more detailed analysis of the information carriers was undertaken to establish what percentages of the instances of information content were presented as a particular information carrier, see Table 5.2 (and also Appendix 4.6).

What: Instances of information in information carriers		Text (%)	Photos of physical models/objects/ people (%)	Photos or scanned sketches (%)	CAD drawings (%)	Images from Internet (%)	Spreadsheets (%)	Video (%)
Study 1	Case 1	√	√	√	-	√	√	√
	Case 2	√	√	√	-	√	-	√
Study 2 and 3 were more detailed, further exploring percentages of instances of information content in information carriers.								
Study 2	Case 3	62	38	-	-	-	-	-
	Case 4	65	21.5	7.25	6.25	-	-	-
Study 3	Case 5	81	3.5	-	14	-	1.5	-
	Case 6	68.5	-	21	-	10.5	-	-

Table 5.2: Information Carriers Used across the Cases

Text was the most common information carrier used to store and exchange instances of information content. It appeared on web pages; in documents; in reports and meeting minutes; and as annotation on sketches. It was the most common method of storing information, but they reported it was time consuming and often hard to describe project work using words alone. *Photographs of physical models/objects/people* were the next most common information carrier. Students regarded this method highly; most often using their readily available phone cameras. Photographs were easy to produce and store; they captured model making/ prototyping and the final solution; they demonstrated how things worked; and they contained valuable *materials information, components & assembly information, contextual information* and *social information*. Photographs were found to require further explanation and were often supported by text on web pages or in documents. Overall students found a multi-media approach most suitable - a combination of text with photographs; text with CAD drawings; or text with sketches.

Fewer instances of information content were found in *CAD drawings, images from the internet* and *spreadsheets*. The sharing and storing of *images from the internet* helped distributed team members realise a shared understanding of the project problem and define project scope. *Spreadsheets* contained project management information - information content on *actions & decisions* and *organisational information on team* and *tasks.* Students expressed a desire to use 3D CAD modelling but had limited time.

In Study 1 video was used by both teams. Video was good at conveying meaning; demonstrating product attributes; hosting Informal information; and it was an informative method for the exchange of information. However students also reported several drawbacks to the use of video. It was time consuming to produce and to view; and once viewed it was not revisited as it was hard to locate and pinpoint specific information. Students noted they would definitely use video on longer projects due to the above noted advantages, suggesting also the use of several short informative clips rather than long video recordings. Students in Studies 2 & 3 did not use video, accrediting this to lack of time in Study 2, and to the use of VC in Study 3. Video contained mainly *social information; contextual information; product/user requirements* and information on how the product solutions functioned.

Review of the information carriers indicated that students had a good understanding of when to use different information carriers to store information content within the design process. For example, most teams used *text* to store *product/user requirements* or *photographs* and *video* to store evidence of physical model making and prototyping. However, their criteria for choice was rather narrow in scope – with most teams noting speed (time taken) and ease, to be the rationale for selection of methods. Quality wasn't mentioned. In one instance poor quality low resolution photographs were quickly taken of sketches since this was easier than seeking out a scanner.

Recent studies have shown that despite the growth in the use of CAD and PDM tools, document use in engineering design still retains a strong physical form (Roy et al., 2004; Wild et al., 2006). This was shown to be the case in the thesis studies; with students choosing traditional project information representations, for example, sketches on paper and physical models; and then digitally converting these to image formats, through scanning or photographing, in order to store and share distributedly. However, as new digital technologies become second nature to newer generations, engineering design students are embracing newer technologies more readily. Four of the six distributed teams stored all information content directly on web pages of shared workspaces; noting they were familiar with wikis and the web environment and that information could be scrolled through and viewed more easily than having to open files and refer to their content.

Recommendations drawn –

- **Recommendation for distributed design to support all information carriers as appropriate to project requirements, e.g. text, sketches, CAD drawings, photographs, video and audio.**
- **Recommendation for students to recognise the advantages and disadvantages of different information carriers and to determine their appropriate use in distributed work.**
- **Recommendation to record video as short clips.**
- **Recommendation to record summary/outcomes of real-time VC sessions. Full transcripts and records seldom revisited due to length.**

5.3.4 Information Valued by Students

The value that teams attribute to the different types of information content varied widely; even across distributed teams which suggests that they are still unsure of the contribution information can make to the development of engineering design solutions and project progress. Educational culture and project goals affected students' perceived value of information content, as evidenced in Case 1. The UK students, typically assessment-focused, valued Formal information more. Whereas the USA students, with a more exploratory set of project goals and objectives, valued the Informal information more. This of course caused conflict.

There was greater consensus across the teams on which Formal information content was *'greatly valued' – market research, materials information, concepts* and *testing, detail design/prototype* and *testing* and the *final solution*. There was less consensus as to which Informal information was valued; although *actions & decisions,* *problems/issues/questions*, and *organisational information on team* were cited as of *'great value'* in most Cases. See Appendix 4.7.

It should be noted that Informal information content valued by students wasn't necessarily the information stored by students; for example, two teams reported they *'greatly valued' discussions* but they noted they would never record and store discussions. This was too time consuming and would seldom be revisited. VC sessions were not normally stored either. Formal information content was more likely to be stored than Informal information content. Informal information is harder to capture. Students were very aware of the time and effort taken to record and store project information, often choosing not to store information due to the effort required. This can contribute to a partial project 'picture' and requires good evaluation skills on the part of students to establish value and worth against effort.

Recommendations drawn –

- **Recommendation for recognition that different types of information will be of greater or lesser value depending on project context and criteria.**
- **Recommendation to evaluate information worth against effort to capture and store.**

5.3.5 Implications for Information Stored

Students are uncertain as to what to store. Today there is a tendency for the 'Google generation' to find far too much information, all too quickly and for this information often to be of questionable quality. Storing distributed design information is challenging. Firstly, in distributed design several of the key context providers for information are missing, for example people, place and time. As such there is the need for greater storing and sharing of Informal information. Educators need to emphasise to students the importance of Informal information to add context, value, meaning and understanding, particularly in a distributed situation. Assessment might be a mechanism for doing this, with one student noting –

> *"We might be encouraged to upload more if we thought we'd get more marks for it* [Informal information]*."* (2.1,v)

Secondly, students reported Informal information can be long and messy, 'cluttering up' the system. It takes time to add or to link existing Informal information to the formal project documentation. Educators and students need to allow additional time to make information meaningful and clear. Thirdly, students found it hard to determine how much information to store; some agreeing all should be stored in case it is required. Others wished to avoid 'information overload'. Worryingly several students thought everything could be stored since storage space was readily available and very cheap. This is counterproductive to good practice in information storing. There are no guidelines on specific quantities of information to be stored on project work due to the complexity of design and the uniqueness of each design project. However, the Recommendations from the Case Studies suggest that in distributed design team-based project work at least 50% of stored project information is Informal information (as a baseline). Fourthly, different teams and indeed sides of teams valued different information content which can further complicate decisions on what information to store. Students need to develop greater skills in self-evaluating information and educators need to build such tasks into project work in addition to guidance and advice.

And finally, students embraced the wide range of information carriers available to them. They used text, photographs, images from the internet, scanned or photographed sketches, video, etc. This range and accessibility can only increase, afforded by future advances in relatively cheap technologies and computing power.

5.4 Information Patterns – *when*?

5.4.1 Uploading of Project Work

The uploading of files into PMs tended to take place around project deliverables and at the end of the projects. Peaks occurred at the end of weekly research, concepts and prototyping stages. This was more noticeable in Study 1 (see Figures 4.7 and 4.16). Contributions to web pages were more evenly spread throughout the projects (see Figures 4.8 and 4.17). Most teams used the wikis and web pages to develop and share project work throughout the project prior to the presenting of formal documents traditionally required from students at each project stage. In distributed design it is crucial that information is recorded frequently throughout project work. Not storing information at the time of generation was shown to weaken collaborative decision making, and slow to project progress. Sides of teams are unable to act effectively on incomplete information.

Some teams experienced prolonged gaps in information exchange with information storing becoming very ‘one-sided’. In Case 2 UK students didn’t receive information for over a week. This not only caused frustration and halted project progress but also led to a questioning of global team commitment and engagement. Information needed to be stored and shared in a timely manner in order not to impact or impede project progress. A lack of storing of information was regarded by these students as a lack of engagement and a feeling of unequal contribution across the global team. The teams who maintained a continuous flow of information (both formal documents and outputs, and Informal information, e.g. *social* and *contextual information*) had a more collaborative experience. In summary frequent storing of distributed information was shown to support team cohesion and collaboration.

5.4.2 Impact of ‘follow-the-sun’ working mode

The Swinburne asynchronous distributed project was designed on the ‘follow-the-sun’ working model. In Cases 3 and 4, with Swinburne, both teams found the experience to be less collaborative than expected. The nature of the design process on this project (task-focused and over a short period of time) contributed to a resultant turn-based working pattern and hindered collaborative design. Each side of the teams worked on a particular stage of the project and uploaded information to their shared workspaces only once. Information was not stored or shared during each side’s design phase; meaning that half of the distributed team was unaware of project progress at any time on the project. Students reported these teams worked more as two sides of a team rather than one global team. They were often unaware of what was happening at the other side of the team.

On the Maltese synchronous distributed projects, information was stored or exchanged more frequently throughout the project - either as uploads to shared online project sites or as VC communications. On synchronous projects less information was stored overall due to increased opportunities for direct f2f contact but the information that was produced was stored and shared more regularly. It was shown that having to meet via VC increased the frequency of information storing. Students acknowledged a requirement to share information in readiness for VC meetings and to record summaries of decisions taken following meetings.

Recommendation drawn –

- **Recommendation to record, store and share information as events happen, or as information is generated, by all global team members, in order to benefit everyone and support distributed collaboration.**

5.4.3 Implications for Information Patterns

Students require to be made aware of the need to store information frequently throughout a distributed project. Failure to do so will cause frustration within global teams; affect team cohesion and trust; and hamper decision-making and project progress.

5.5 Information Strategy – *how*?

5.5.1 The Need for a Strategy and Rules

'Remoteness' makes the management of information particularly complex and the need to establish rules and develop a strategy even greater due to the lack of opportunities for direct discussion and increased potential for misunderstanding. Research has shown that students are weak at the initial planning and workflow management stages, e.g. they often begin their investigation of the problem without effective goal setting and strategy planning (De Corte, 1999; Oliver, 2001). As a result of not preparing a strategy or protocol for information storing at the start of the project distributed teams experienced times when information could not be located; leading to confusion, duplication of information and difficulties in sharing. Students reported that information storing for the majority of the teams evolved as the project progressed. Examination of their project sites showed that in most cases it could be regarded as ad hoc. Students noted that lack of time contributed to a strategy or rules not being made and stored. The time spent establishing a strategy and rules, at the beginning of a project, would have been recouped over the length of the project.

Case 3 (asynchronous) highlighted two further issues which influenced a lack of the development of a distributed information storing strategy. Firstly, UK students felt that they needed to know their global partners before a strategy could be developed jointly. Socialisation was limited and no photographs were exchanged, in this case. Secondly, as in other cases too, rather than discussing a joint strategy and plan for project and information management, the UK-sides initiated the online project sites

,inviting their global partners to work (via email). Shared online project sites were set up and consequently many ‘rules’ were inherent or implied by the UK initiators before the global partners engaged. The teams carrying out synchronous project work, as in Case 5 and 6, didn’t feel they needed to create ‘rules’ or a strategy since they could discuss information f2f readily (Mq) or advise quickly via email (M2.2,v). Establishing of joint rules early on can help promote joint ownership and team cohesion.

Students noted they found it difficult to predict exactly how they should store their project information before engaging in collaboration (due to inexperience). However, they felt that any strategy should be flexible and capable of being amended and adapted, dependent on requirements as projects developed. On reflection, having experienced a Global Design Project all students felt that discussing and storing an information strategy at the beginning of the project would have helped prevent some of the emergent issues and saved considerable time best spent on other design activities. UK students in Case 2 reported –

> *“It was a mistake not to discuss and record the ‘rules’ for project and team management before starting the project”.* (6.3,rr)

Recommendation drawn –

- **Recommendation for global student teams to establish rules for storing of distributed project information – what to store (content & information carriers); where to store information (tools); how to store it (organisation/who) and when to store it (working patterns).**

5.5.2 Structuring and Organising Information

Previous work of the author (Grierson et al., 2005), and studies in industry (Davis et al., 2001) have shown the importance of structuring project information. Organised information can be turned around more effectively and efficiently allowing informed decision-making. By the end of each Global Design Project, teams had organised project information in some manner to varying degrees. For example, in Study 1, Team 6 had used wikis to structure their files which were stored in unorganised file galleries. Other teams, Team 5 in Study 1 and Team 2 in Study 2, had organised project information on long wikis, by design stages, in a chronological order. Whilst this was found to be satisfactory over the short duration of the Global Design

Projects, it would prove far more problematic when working on longer projects with larger collections of information. The complexity of organisation and structure increases with quantity of information.

Earlier studies the author has been involved in, have shown that information and knowledge structuring is not completely natural to students and that they may need preparation for this task especially in the context of specific types of digital environments, for example in shared workspaces and digital repositories. Use of wikis, as in the Nicol et al., (2005) studies showed that wikis provided an ideal platform for students to structure and organise their information and knowledge.

Recommendation drawn –

- **Recommendation for distributed design information to be structured and organised.**

5.5.3 Clarity and Richness of Information

In distributed design there is a greater need for information clarity due to the lack of opportunities for explanation and discussion; and the absence of key context providers such as people, places and time. By its very nature, some design information can be very ambiguous and messy. However, content needs to be understandable, comprehensive, clear and succinct for teams to be more efficient and productive. At times, during the Studies, teams found that information wasn't sufficiently clear. This lack of clarity often led to delays, confusion and frustration.

In Cases 3 and 6, students noted that information had to be very specific; everything should be clarified; nothing should be assumed; and that things had to be made more obvious in distributed work than in collocated project work. (2.1,v;M3.2,v) Time was found to impact on information clarity. The shorter the project the less time there was available to ensure information clarity in terms of detail and presentation.

Ensuring that information was clear to distributed partners engaged students in deeper cognitive activities. The UK students in Case 3 reported that it took time to make information more concise whilst at the same time keeping it as informative as possible. *"This forced our side of the team to think harder."* (2.2,rr) Several teams reported that storing project information as a series of short descriptive summarised processes proved valuable, allowing a 'story' of the project to be told to distributed partners. The value of stories as a means of the exchanging of information is well documented (Schank, 1990; Davenport & Prusak, 1997; Lloyd, 2000).

Recommendation drawn –

- **Recommendation for distributed design information to be unambiguous and clear.**

5.5.4 Adding Context

As noted previously, in virtual space the positive effects of tacit knowledge transfer are severely reduced. As such, information with context becomes increasingly more desirable. Students found they needed to record and store more context and justification behind ideas or how things worked, during distributed design, compared with collocated design, in order to avoid misunderstandings or ambiguities. Students in Case 4 reported they *"…needed to explain more when in an asynchronous situation"*. (3.2,v) Formal information and documentation alone was not enough. Informal information can add meaning and context, making for a richer description of the design process; but storing of this information takes further effort and time. UK students in Case 3 noted they valued their Swinburne team members' rationale for changes and good timely feedback. By documenting more of the design process, methods and failures; recording *actions & decisions* and making their *design rationale* more explicit, students increased Informal information content.

Linking information or clustering it with other information has been shown to give information greater meaning. In Nicol et al.'s studies, creating relationships between nuggets of information not only helped students construct a clearer picture of the project problem but it afforded greater meaning to the information when viewed out of context or at a later date (Nicol et al., 2005). Previous work also shows that distributed teams need multi-modal communication channels to provide context for the interpretation of remote information (Perry et al., 1999). Students found the informal information content contained in emails or other communications, for example, *actions & decisions, problems/issues/questions, social* and *contextual information*, helped to clarify information in files, documents and on web pages. It would be beneficial to link the Formal information in repositories to the Informal information stored in communications technologies to give added context and meaning.

So, a conflict arises between the need for distributed information to be more concise whilst at the same time richer and more detailed. Additional time and activities designed into distributed project work can help student teams achieve both aspects.

Recommendations drawn –

- **Recommendation for information to be richer and more detailed in a distributed situation than in a collocated situation.**
- **Recommendation for information with more context.**
- **Recommendation that since communications tools stored valuable Informal information that this information be regarded as part of the store or linked to the repository.**

5.5.5 Interaction with and Reflection on Stored Information

Earlier class studies by the author in a different context, showed better concepts were generated by student teams who interacted more with the stored resources (gathering, editing, analysing and applying) and who reflected on the resources regularly during the design process (browsing initially for ideas and returning to target more specific information) (Grierson et al., 2005).

Re-visiting of stored information during the distributed projects was limited across all six cases. Students reported stored work was not often re-visited due to lack of time. If projects had been longer they noted they would have been more likely to reflect. This may or may not be the case; as students do not naturally reflect during project work. Of all the information content, students reported *market research* and *concepts* were the most re-visited. They were reviewed in order to progress the project to the next stage and make improvements. The work of distributed partners was reviewed but students did not often reflect back on their own stored contributions. Students tend to focus on finding content, rather than reflecting on and evaluating its significance relative to the problem in hand and to project progress (Nicol et al., 2005).

As part of the Global Design Class, UK students were required to take part in class reflective activities and to write a report reflecting on their distributed design project experiences. The PM proved most useful for this purpose. It helped "*…jog our memories a bit*". (3.2,v) For greatest effect students should be encouraged to engage in reflective activities during project work.

Recommendation drawn –

- **Recommendation for interaction with and reflection on stored project information during project time for increased student learning.**

5.5.6 Implications for Information Strategies

The nature of design necessitates the use of a wide range of information content types across many information carriers. Added to this, 'remoteness' makes the management of distributed information even more complex. Without a clear strategy, or rules for storing and sharing distributed design information the quality of project information can be affected. Information can be lost or duplicated; be inappropriate or untimely, resulting in a lack of project direction, time wasting, confusion and disagreement and, in some cases a poorer product outcome. Time at the beginning of projects needs to be set aside, not only to understand the project scope and problems; to socialise with distributed team members and to familiarise with technologies to be used; but also to determine how distributed information will be handled. There is a greater need for making information clear in distributed design work due to the lack of opportunities for explanation and discussion. As previously discussed, Informal information has been shown to be a good means of adding meaning, context and richness. However it is time consuming to store.

Unstructured or unorganised project information caused frustration, confusion and misunderstanding amongst several of the distributed team members. If consideration is given to the structuring and organising of distributed design information early on in project work, information storing, sharing and retrieval will be easier and less time consuming. Information can be given increased meaning by linking it or clustering it to other information and creating relationships between 'nuggets' of information which can give greater meaning when viewed out of context. The process of organising project information and resources is beneficial. It encourages students to think. Organised and structured information can be turned around effectively and efficiently, allowing others to work based on decisions made. Graduates who have these organisational abilities will be better prepared for industry.

Maintaining an online store of project information or a PM is critical for project interaction and reflection. Construction of resource collections contributes to learning by requiring students to analyse, organise and reflect on their knowledge, and that of others (Denard, 2003). Interaction with information keeps team members updated during a project; helps them visualise what others in the team are doing and promotes a feeling of collaboration. Reflection is recognised as valuable for informing performance improvement; for learning and for development. Educators need to make students aware of the educational benefits of maintaining an ongoing collective PM e.g. a shared understanding of project problems; team awareness; reflection; learning from past experiences (even failure); and preparation for industry.

5.6 Summary

Chapter 5 discussed the emerging Issues from the Case Studies making a series of Recommendations to support distributed design information storing. A Summary of all Issues and Recommendations can be found in Table 5.3.

From the findings of the Studies it was evident that students undertaking distributed design team work require additional guidance to help overcome the issues associated with storing distributed design information; for example, lost and incomplete information; lack of context; poor communication; lack of team trust, etc. The case for a centralised information storing tool (a Project Memory); the need to be familiar with the technologies and to be aware of where information lay, were established. The need to store informal information and the need to store appropriate amounts of information were explored alongside the use of the different information carriers students used. The requirement for an information storing strategy; the organising and structuring of information; the clear communication of rich information with context; and the need for students to interact with and reflect on stored information during project work was also discussed.

The Recommendations, generated from the Studies and the literature, underpinned the development a set of initial guiding Principles to support good practice in distributed design information storing. The development of these Principles will now be presented in Chapter 6 and then validated in Chapter 7.

Table 5.3: Summary of all Issues, Findings and Recommendations from Cases

ISSUES and FINDINGS from Cases	RECOMMENDATIONS	
• Information stored in different places resulted in delays in finding information. • Access to information at all times was beneficial. • It was confusing having several ways or places to store information. • Using too many systems meant information became fragmented and duplicated.	• *Recommendation for centralised information storage in distributed design team work.*	**Information Systems – 'where'**
• Recording information was time consuming. • Information storing and communication systems worked well together. A synchronous team noted the reverse too – a communication tool alone is not sufficient; an information storing tool is also required. • Difficulties with information storing contributed to a lack of communication.	• *Recommendation for tools to satisfy distributed information storing needs, including adaptability.* • *Recommendation for communications tool to support information storing tool.*	
• Simple systems with an acceptable learning curve were preferred by students.	• *Recommendation for selected tool(s) to be simple to use so as not to interfere with the design process.*	
• Teams found being unfamiliar with system problematic. • Time is needed to become familiar with system prior to project start. • Unequal systems competencies caused inequality within teams.	• *Recommendation for all global students to be familiar with tools prior to the start of the project.*	
• Information stored in 'temporary' locations was lost to teams. • One tool only stored information for a limited time; thus losing project information before report writing.	• *Recommendation for selected tool(s) to retain information and for it to be accessible for the duration of the distributed project, and beyond for academic purposes (e.g. student reflection, staff re-use, external assessment and research).*	
• Time was lost locating and finding information. • Access to information storing systems was initially confusing and caused delays. • There was some initial confusion as to where information lay. • Lacking or missing information caused delays.	• *Recommendation for all global students to be able to find information easily and quickly.*	

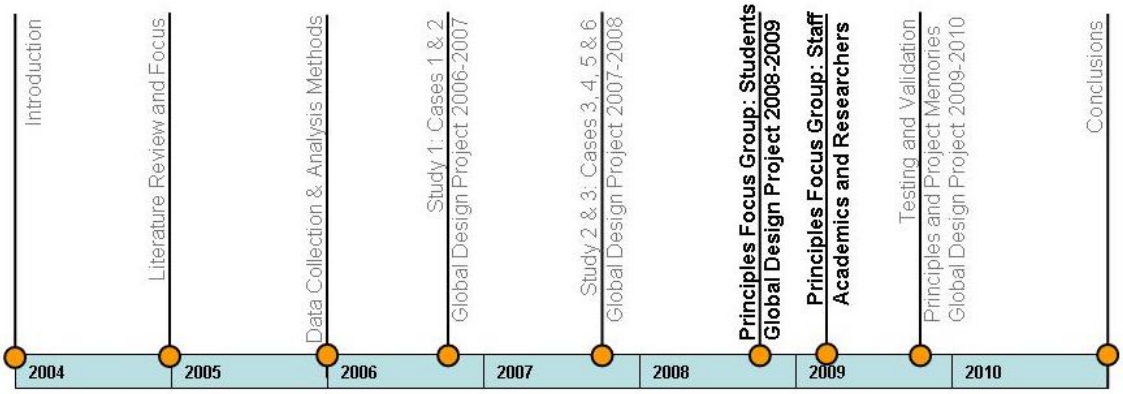
• Lack of recording of informal information created an incomplete ‘picture’ in some cases. • Amounts of information stored varied across teams. • Students were unsure of what to store – too much or too little. • Not all information had been stored by teams. • Less Informal information was stored on synchronous projects due to greater opportunity to discuss via VCs. • UK-sides stored more than distributed partners. This caused frustration in some teams.	• *Recommendation to store and record a comprehensive ‘picture’ of project problems, processes, rationale and outcomes.* • *Recommendation that not all information needs to be stored; avoid information ‘overload’.* • *Recommendation to avoid information ‘under load’.* • *Recommendation to contribute equally across distributed sides of a team to avoid inequality and frustration.*	**Information Stored – ‘what’**
• Students traditionally store formal documents required as deliverables or final solutions, which are invariably tied into assessment. • Storing *functional information*, *product/user requirements* and *materials information* helped reach a shared understanding on projects. • Students find storing Informal information time consuming. • Students reported they would store more informal information if they received more marks. • Students recognise the importance of design rationale and contextual information in distributed design. • Students felt more information could have been stored on the design process.	• *Recommendation that Formal information is stored on the product.* • *Recommendation that Informal information is stored on product, process and people in order to support development during the project and add meaning to the Formal documents.*	
• Across all systems, almost equal, or more Informal information was stored in the Project Memories. Students did not expect this. • Files contained more Formal information – e.g. final solution and deliverables. • Wikis were valuable for storing Informal information. • Emails contained high %s of Informal information content.	• *Recommendation that at least half of information stored is informal to add context and meaning to formal documents.* • *Recommendation to store more Informal information when working asynchronously.*	
• The information ‘valued’ by students wasn’t necessarily the information stored by students. Valued Formal information content was more likely to be stored than valued Informal information. • There was greater consensus across the teams on which Formal information content was valued. Less consensus on which Informal information was valued. • Culture affected value; e.g. UK students ‘valued’ Formal information more; USA students ‘valued’ Informal information more.	• *Recommendation for recognition that different types of information will be of greater or lesser value depending on project context and criteria.* • *Recommendation to evaluate information worth against effort to capture and store.*	**Information ‘valued’**

• *Text, photographs of models/objects/people, photographs of scanned sketches* and *video* were the most common information carriers. • Text documents and images were richest in information content. • Photographs made for good evidence and were quick and easy to produce and store. • Students found it hard to be clear and concise using text alone. Text and photographs; or text and sketches or 2D CAD sketches were a good combination. • Video was good for exchanging information but was time consuming to produce or view on a short project. • Key points from VC meetings were recorded and stored, but not VC sessions. Students noted these would not be revisited due to time.	• *Recommendation for distributed design to support all information carriers as appropriate to project requirements, e.g. text, sketches, CAD drawings, photographs, video and audio.* • *Recommendation for students to recognise the advantages and disadvantages of different information carriers and to determine their appropriate use in distributed work.* • *Recommendation to record video as short clips.* • *Recommendation to record summary/outcomes of real-time VC sessions. Full transcripts and records seldom revisited due to length.*	**Information Stored – 'what'**
• The more formal project information tended to be stored on completion of key stages. • Wiki changes were slightly more evenly spread across project duration. • Decisions were dependent on timely information. • Generally one person on each side stored project information. • Asynchronous work created a distinct start-stop storing of information by each side of a team. Two independent sides evolved carrying out and exchanging concept designs. • Information storing format of initiating side of team is followed by other side. • Synchronous work was far more collaborative. Information tended to be stored more continuously. • This team also felt turn-based nature of asynchronous design contributed to the lack of a joint information storing strategy.	• *Recommendation to record, store and share information as events happen, or as information is generated, by all global team members, in order to benefit everyone and support distributed collaboration.*	**Information Storing Patterns – 'when'**
• Information storing was often ad hoc. • Most teams did not discuss rules for storing project information before the project start. • Information storing evolved. • One team felt that in order to discuss information strategy they needed to know all global team members. • A contributing factor to no strategy or rues was lack of time. • Any strategy should be flexible and capable of being adapted to some extent, dependent on information storing requirements as project work develops.	• *Recommendation for global student teams to establish rules for storing of distributed project information – what to store (content & information carriers); where to store information (tools); how to store it (organisation/who) and when to store it (working patterns).*	**Information Strategy – 'how** and **why'**

• Lack of organisation and structure to project information caused frustration and confusion. • Students recognised need for organising and structuring. • Students find structuring information hard. • Few teams had structured their Project Memories – some by time, on wikis/web pages, others by design stages.	• *Recommendation for distributed design information to be structured and organised.*	**Information Strategy – 'how** and **why'**
• Asynchronous design required information clarity; ambiguity had to be reduced; nothing could be assumed. This was additional to collocated work. • Making information more concise and informative took time but this forced students to think. • Clarity and completeness of information was affected by short project timescales.	• *Recommendation for distributed design information to be unambiguous and clear.*	
• More context was needed in asynchronous work. • Distributed information requires more explanation.	• *Recommendation for information to be richer and more detailed in a distributed situation than in a collocated situation.* • *Recommendation for information with more context.*	
• Informal information exchanged via communication tools helped clarify information in files and on web pages. • Need to keep communications levels high.	• *Recommendation that since communications tools stored valuable Informal information that this information be regarded as part of the store or linked to the repository.*	
• Students reported not referring back to information much.	• *Recommendation for interaction with and reflection on stored project information during project time, for increased student learning.*	

Table 5.3: Summary of all Issues, Findings and Recommendations from Cases

6 Development of a set of guiding Principles



6.1 Introduction

Chapters 6 & 7 address Research Question 2 - *How can students be encouraged and supported to record project work in a distributed design context?* Based on the outcomes of the descriptive studies, Chapter 6 will now focus on the third stage of the work – *Prescription*, the development of the set of guiding Principles and Principles Framework to support good practice in distributed design information storing. The Principles are derived from the Recommendations for distributed design information storing, underpinned by both the findings and issues of the six detailed Case Studies, and supported by the literature in the field, see Figure 6.1.

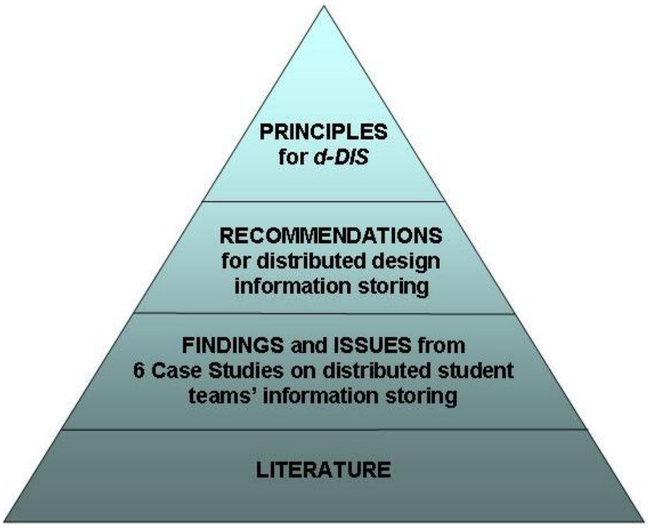


Figure 6.1: Derivation of Principles for d-DIS

6.2 Rationale for Principles

The key motivation for the Principles is straightforward: to prepare today's students for the management of distributed design engineering information in a rapidly expanding globalised society and economy; and to support educators in this goal. The Principles are intended for use by both students and educators in distributed-design contexts to improve information co-ordination and as a result enhance both distributed collaboration and communication. This of course does not exclude the use of the Principles in industry-related applications, however the focus of this work is the academic environment.

By definition a principle is -

> *"a basic truth or law or assumption; a generalisation that is accepted as true and can be used as a basis for reasoning or conduct."*
>
> (audio English.net[16])

Work by others in higher education has shown principles to be effective in supporting good practice and engaging and empowering students - the seven Principles of Good Feedback Practice in Undergraduate Education (Chickering & Gamson, 1991) and more recently the eleven Principles of Good Assessment Design ((Nicol, 2007) adapted from (Nicol & Macfarlane-Dick, 2006) and (Gibbs & Simpson, 2004)). Other related research, within the manufacturing sector, has established a set of 5 Principles for Lean Information Management. Through the development of these principles, Hicks (2007) highlights a relative lack of overall principles for improving information management. He argues that there are many tools and methods for improving particular aspects of information management but few general methods or principles that can be applied to information management and its range of activities. Most recently the Knowledge and Information Management (KIM) Grand Challenge Project has developed a set of eleven Principles for the Through-Life Management of Engineering Information (McMahon et al., 2009). This work adds to these Principles, focusing on the storing of engineering design information and in particular the aspect of 'distributedness'.

---

[16] www.audioenglish.net/dictionary/principle.html

The argument for the development of a set of principles is strong. In their book on information ecology, Davenport and Prusak note that a simple and straightforward approach to building an information strategy could involve the use of principles, or statements of direction and position on key issues. Principles support a dialogue on information management (Davenport & Prusak, 1997). There is also pedagogical rationale: principles have been shown to support good practice in higher education (Chickering & Gamson, 1991; Nicol & Macfarlane-Dick, 2006; Gibbs & Simpson, 2004 and Nicol, 2007). They add rigour, underpinned by the literature and evidenced-based research. Additionally there is the recent surge of interest in both academic research and industry in their development and use. Principles have been adopted in this thesis specifically, for a number of reasons -

1. Firstly, they have broad relevance and flexibility. Studies on mechanical engineers show that designers following a 'flexible-methodical procedure' tended to produce good solutions (Fricke, 1993, Fricke, 1996). They are neither too narrow nor too specific and are capable of implementation in many ways. As such they can be used by both students to improve and develop good practice in distributed design information storing and by educators when designing distributed information storing activities for a wide range of classes and projects. They are capable of being implemented in many ways dependent on such factors as the project task(s); the project goal(s); the project context, etc. The manner in which they are used in practice is also variable, dependent on the student; the team; the educator(s), etc. A 'tight-loose' approach to the implementation of principles is recommended; with educators maintaining the educational intent behind the principles (tight) and the techniques of implementation being adaptable to the teaching and learning context (loose) (Thompson & Wiliam, 2007). In terms of information management principles should provide a generic framework which supports and directs an improvement programme and philosophy (Hicks, 2007).
2. Secondly, they are derived from both the literature in distributed design and information management and the evidence-based research from the 6 Case Studies. As such they should help guide and inform good practice in the field.

3. Thirdly they are simple and easy to understand. Others note the virtue of principles is their simplicity and common sense in helping an understanding of key information issues (Davenport & Prusak, 1997).
4. Fourthly, they help identify key factors impacting on distributed design information storing. The principles have been defined independently with minimal overlap, although as explained below there will certainly be some element of overlap due to relationship complexities. Each Principle has been given a unique name and explanation for ease of understanding and application. This helps students to focus on the importance of managing each aspect of distributed information and knowledge and to improve student information storing processes and skills.
5. And finally, not all principles need be applied at one time. Some principles will be more effective than others in specific situations and applications. However, their effectiveness should be greater when more principles are operational (Nicol, 2007). The more principles applied, the greater the opportunity for the principles to mutually support each other.

The need for the Principles has derived from the literature and the evidence-based Case Studies presented earlier. Use of the Principles aims to support students and help them to –

1. develop a distributed information strategy;
2. manage and share project information, knowledge and resources;
3. create a rich and meaningful project story – *Project Memory*;
4. interact and reflect on a more comprehensive *Project Memory*;
5. achieve a shared understanding of project problem through increased storing of informal information; and
6. improve distributed information storing skills.

The Principles' aims fall into three key categories, see Table 6.1 -

1. **Management** - Manage project information and resources
2. **Content** - Create content in the shared *Project Memory*
3. **Learning** - Engage students in learning processes.

Need from Literature	**Use of Principles help to -**		
Insufficient planning – De Corte, 1999 Hertel et al., 2005	• develop a distributed information strategy	**Improve storing of distributed design information** (improve processes)	**Manage project info**
Weak at managing and structuring project resources – Denard, 2003 Grierson et al., 2004 Nicol et al., 2005	• manage and share project information, knowledge and resources		
To support distributed design, both asynchronous and synchronous collaboration, it is crucial to provide an archive or repository that functions as a collective memory - Gross et al., 1997	• create a rich and meaningful project 'story' – *Project Memory*	**Improve storing outputs** (improve product)	**Create content**
Interact and reflect on information for learning – Schon, 1983 Kolb, 1984 Valkenburgh & Dorst, 1998	• interact and reflect on a more comprehensive *Project Memory*	**Improve learning achievements** (improve learning)	**Engage with Learning**
Shared understanding – Hinds & Weisband, 2003 Increase informal information – Huet, 2006; Conway, 2008	• achieve a shared understanding of project problems through increased storing of informal information		
Students require advanced skills in digital resources - Holden, 2003	• improve distributed information storing skills		

Table 6.1: Principles support Processes, Products and Learning

For greatest impact, the Principles should be used by educators when designing distributed class activities or distributed project work to improve –

1. student distributed-design information storing processes;
2. the distributed-design information storing product - the *Project Memory*, and,
3. student learning; through opportunities for students to engage in greater interaction and reflection on the *Project Memory*.

Additionally implementation of the Principles should increase satisfaction with distributed design project processes; i.e. less expressed frustration and confusion during distributed design project work.

6.3 Development Process

Underpinned by the findings from the descriptive Case Studies and subsequent Recommendations, the Principles developed through a number of versions; see Figure 6.2.

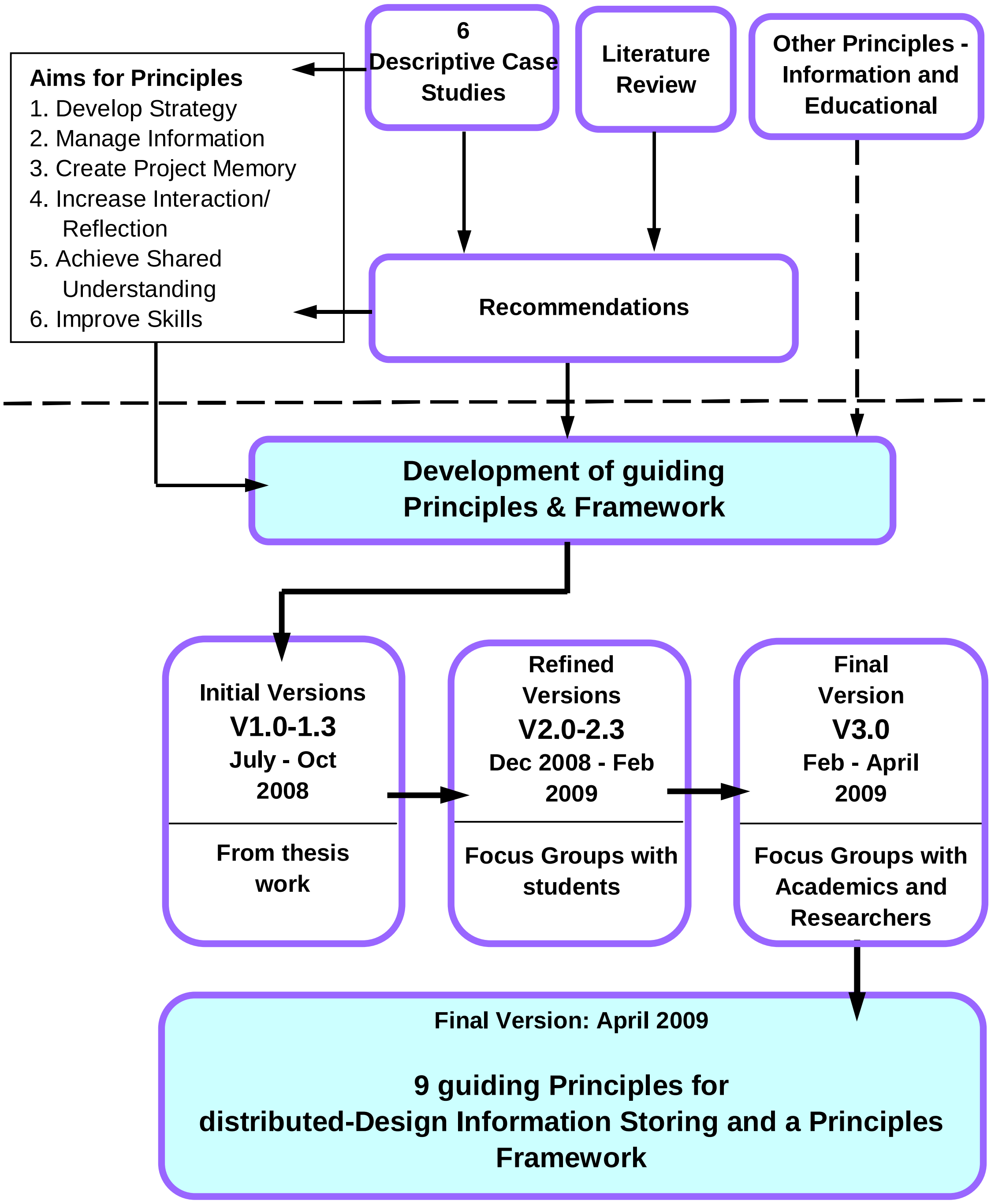


Figure 6.2: Heuristic Framework for the Principles for d-DIS

- ***Initial Versions 1.0-1.3*** - July – October 2008:

Several iterations of the Principles were developed from the clustering of the Recommendations under emerging themes and discussed with PhD supervisor. Originally the Principles were referred to as guidelines but it was felt that Principles were a more persuasive and powerful tool, particularly in education.

- ***Refined Versions 2.0-2.3*** - December 2008 – February 2009:

Version 1.3 was refined, again through iterations, following input and feedback from Focus Groups of students who had experienced distributed project team work.

- ***Final Version 3.0*** - February 2009 – April 2009: final version.

Academic and research staff, all experts in the fields of either distributed design or information management, gave feedback on Version 2.3 from a practical and educational perspective. This was further developed based on their feedback to form the Final Version of the Principles. Development will be discussed below in detail.

6.3.1 The Initial Principles

Twenty nine key Recommendations were identified from the six Case Studies for improving distributed design information storing. These had to be reduced to smaller more manageable groups under themes which would form the basis for potential Principles; see Tables 6.2 and 6.3. Clustering was the method used to further refine the Recommendations into themes for the Principles. Clustering is a visual and iterative method used to inductively form categories through iterative sorting (Miles & Huberman, 1994).

Early Classification Categories	**New Emerging Themes**	
information storing systems - where?	1.	Tools
	2.	Information Awareness
information storing - what?	3.	Information Types and Amounts
	4.	Information Media/Format Types
information patterns - when?	5.	Regular Storing Throughout
information strategy - how?	6.	Strategy and Rules
	7.	Organised, Structured and Unambiguous
	8.	Add more Context for Greater Meaning
	9.	Interaction and Reflection

Table 6.2: Themes forming the basis of the Principles

Recommendations	Focus/ Emerging theme
• *Recommendation for centralised information storage in distributed design team work* • *Recommendation for tools to satisfy distributed information storing needs, including adaptability.* • *Recommendation for communications tool to support information storing tool.* • *Recommendation for selected tool(s) to be simple to use so as not to interfere with the design process.* • *Recommendation for all global students to be familiar with tools prior to the start of the project.* • *Recommendation for selected tool(s) to retain information and for it to be accessible for the duration of the project, and beyond for academic purposes (eg student reflection, staff re-use, external assessment and research).*	Where? **Tools**
• *Recommendation for all global students to be able to find information easily.*	Where? **Information Awareness**
• *Recommendation that Formal Information is stored on the product.* • *Recommendation that Informal information is stored on product, process and people in order to support development during the project and add meaning to Formal documents.* • *Recommendation that at least half of information stored is informal to add context and meaning to formal documents.* • *Recommendation to store more Informal information when working more distributedly.* • *Recommendation to store and record a comprehensive 'picture' of project problems, processes, rationale and outcomes.* • *Recommendation that not all information needs to be stored.* • *Recommendation to avoid information overload.* • *Recommendation to contribute equally across distributed sides of a team to avoid inequality and frustration.* • *Recommendation for recognition that different types of information will be of greater or lesser value depending on project context and criteria.* • *Recommendation to evaluate information worth against effort to capture and store.*	What? **Information Types and Amounts**
• *Recommendation for distributed design to support all information carriers as appropriate to project requirements, e.g. text, sketches, CAD drawings, photographs, video and audio.* • *Recommendation for students to recognise the advantages and disadvantages of different information carriers and to determine their appropriate use in distributed work.* • *Recommendation to record video as short clips.* • *Recommendation to record summary/outcomes of real-time sessions. Full transcripts and records seldom revisited due to length.*	What? **Information Media/Format Types**
• *Recommendation to record, store and share information as events happen, or as information is generated, by all global team members, in order to benefit everyone and support distributed collaboration.*	When? **Regular Storing Throughout**
• *Recommendation for global student teams to establish rules for storing of distributed project information – what to store (content & format); where to store it (tools); how to store it (organisation/who) and when to store it (working patterns).*	How? **Strategy and Rules**
• *Recommendation for distributed design information to be structured and organised.* • *Recommendation for distributed design information to be unambiguous and clear.*	How? **Organised, Structured, Unambiguous**
• *Recommendation for information to be richer and more detailed in a distributed situation.* • *Recommendation for information with more context.* • *Recommendation that since communications tools stored valuable Informal information that this information be regarded as part of the store or linked to the repository.*	How? **Add more Context and Greater Meaning**
• *Recommendation for interaction with and reflection on stored project information during project work for increased student learning.*	How? **Interaction and Reflection**

Table 6.3: Drawing out the Key Principles for d-DIS

From this reduced clustering an initial set of nine guiding Principles were produced, see Table 6.4. Each Principle helps to guide and inform good practice on a particular aspect addressing the issues from the literature and the Case Studies. The Principles are 'high-level' to allow for flexibility of implementation.

	Good practice -	*Cluster/ Theme*
1	Emphasises the need for global team project information strategy (creation of rules) early on.	*Strategy and rules*
2	Encourages storing of organised, comprehensive and unambiguous project information.	*Organised, structured and unambiguous*
3	Emphasises selection and familiarisation of tool(s) before project start.	*Tools*
4	Encourages a team awareness of where information is stored.	*Information Awareness*
5	Establishes what information content to store and how much.	*Information types and amounts*
6	Establishes what information formats to store.	*Information formats*
7	Encourages storing of informal information to add richness and understanding.	*Add more context and greater meaning*
8	Encourages regular storing of project information throughout project by both sides of distributed team.	*Regular storing throughout*
9	Encourages reflection and interaction with stored information.	*Reflection and Interaction*

Table 6.4: Initial 9 guiding Principles for d-DIS

6.3.2 The Initial Principles Framework

The Principles were then mapped to a Framework relating to project stages – pre-project work; during project work and post-project work, see Figure 6.3. Principles 1 & 3 emphasise the creation of a strategy or rules and the familiarisation with project tools, before the project start. Principles 5, 6 & 7 indicate the need for an information-centred core to project work which includes both formal information of appropriate content and media type, and informal information to add richness and understanding. The author defines this core as the *Project Memory* (Grierson et al., 2006). The circular arrows around the Project Memory indicate that Principles 2, 4, 8 & 9 should be continually applied during project work. Information should be organised, comprehensive and unambiguous. Every team member should be aware of where to store project information and consequently where to find project information. Distributed project information should be stored frequently by all team members during project work.

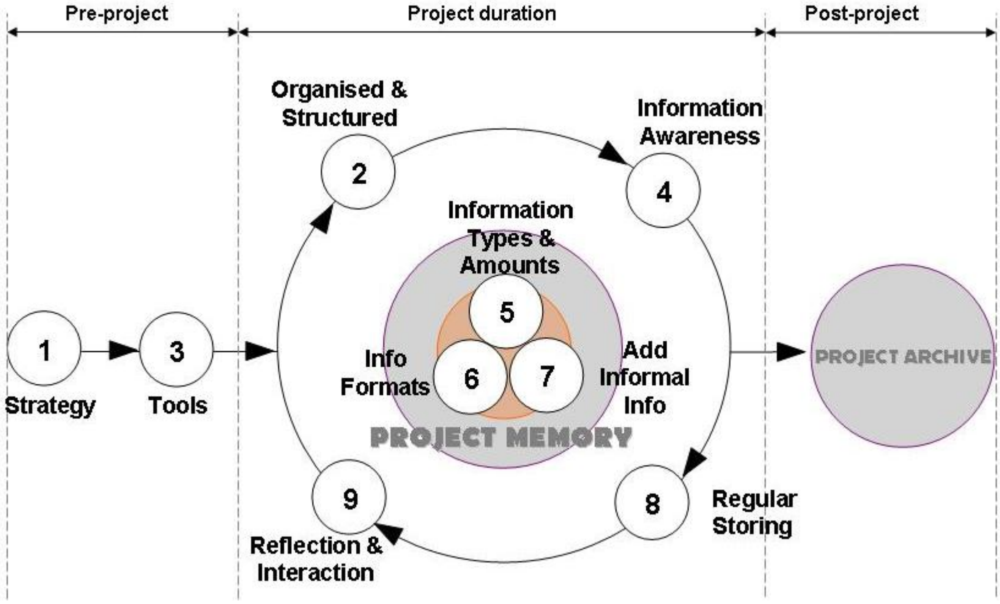


Figure 6.3: Initial distributed-Design Information Storing (d-DIS) Framework

Most importantly, in terms of educational value, the stored information should be reflected upon and interacted with throughout the project rather than just at milestones. The importance of reflection for those working in professional practice is well recognised (Schon, 1983; Valkenburg & Dorst, 1998). Researchers such as Kolb and Cowan have shown that learning can be enhanced when it is organised around cycles of learning activity and reflection (Kolb, 1984; Cowan, 1998).

6.4 Focus Group Feedback and Principles Development

Focus groups were held to obtain feedback on the Principles for distributed design information storing and the Framework from students and teaching staff, knowledgeable in, or with previous experience of, distributed design. It is acknowledged good practice to elicit feedback which can help validate developmental work (Denzin, 1978). The feedback received not only endorsed the need for guidance for students and academics for distributed design information storing but also helped further develop the Principles and Framework.

6.4.1 Focus Group Design

Four focus group meetings took place: two student focus groups and two teaching staff focus groups.

Group Size and Participant Numbers

Several considerations were taken into account when designing the number of focus groups and number of participants. The number of students with global design experience was limited; e.g. the 2008-2009 Global Design Class students numbers (from which participants were drawn) was thirty one. Teaching staff numbers were also low: twelve academics and researchers with relevant experience and backgrounds were identified from DMEM and CAPLE (Centre for Academic Practice and Learning Enhancement) at the University of Strathclyde, Glasgow. Student and staff availability was restricted due to timetabling and participation was on a voluntary basis. Numbers were such that potentially three focus groups for students and three focus groups for teaching staff could have taken place. It was decided however to keep the number of focus groups to four, designing in an element of over recruiting which can often be advantageous (Wilkinson, 1999). Students in particular often fail to attend after signing up. The number of participants in the focus groups falls within acceptable ranges of 4-10 (Wilkinson, 1999).

Participants

The student participants were either Postgraduate Global Innovation Management (GIM) students or 5th year Product Design Engineering (PDE) students from the Global Design Class 2008-2009 at DMEM, who had experienced Global Design Project work. They signed up for one of the two focus groups, planned on separate days to suit students' timetables. There were nine students in Focus Group 1 and eight students in Focus Group 2 (one student failed to attend on the day). Each Focus Group lasted 75 minutes. See Appendix 6.1 for the Global Design Students' Focus Group Outline Plan. A further two Focus Groups were held with academics and researchers who were selected on the basis of their expertise related to the thesis - distributed design, information management or both. Eight academics and researchers were available to take part from the twelve invited. See Appendix 6.2 for coding used to identify participants in data. Feedback lasted approximately 80 minutes and took a similar format to the student focus groups.

The Process

Background research on the issues of distributed design information storing from the case studies, was presented to each focus group, including an overview of the derivation of the Principles. Consent to take part was then obtained. Participant Information Sheets and Consent Forms were used, see Appendix 3.2.

The data was built up in three stages affording participants the time to work with and familiarise themselves with the research work before engaging in small group discussion and then in open discussion. Participants were first asked to agree or disagree with each of the Principles individually, giving reasons and noting their responses on paper. Secondly, in small groups (of three students; and of two staff), comment was elicited on any gaps and thoughts on the Framework requested. The session concluded with a 15-minute open discussion involving participants, prompted by author-composed semi-structured questions. The open discussion allowed participants the opportunity to engage in interactive discussion and helped further develop the Principles and the Framework through suggested improvements and methods of implementation in class. The open discussion was voice recorded so that the author could facilitate the group, take notes and identify speakers. These recordings were transcribed to add to the data and support development of the Principles. Detailed feedback follows in Sections 6.4.2, 6.4.3 and 6.4.4.

6.4.2 Student Focus Group Feedback

Individually, students were asked to agree or disagree with each Principle; see Figure 6.4 for all results. Similar results were returned across the two Focus Groups for each Principle, which in itself supported validation of the findings. See Appendix 6.3. There was a difference of opinion on only two of the Principles between Focus Groups 1 and 2 – Principle 5 on *which information content to store and how much*, and Principle 7 *on the storing of informal information*. Students lacked consensus on what to store and were uncertain as to exactly what informal information was.

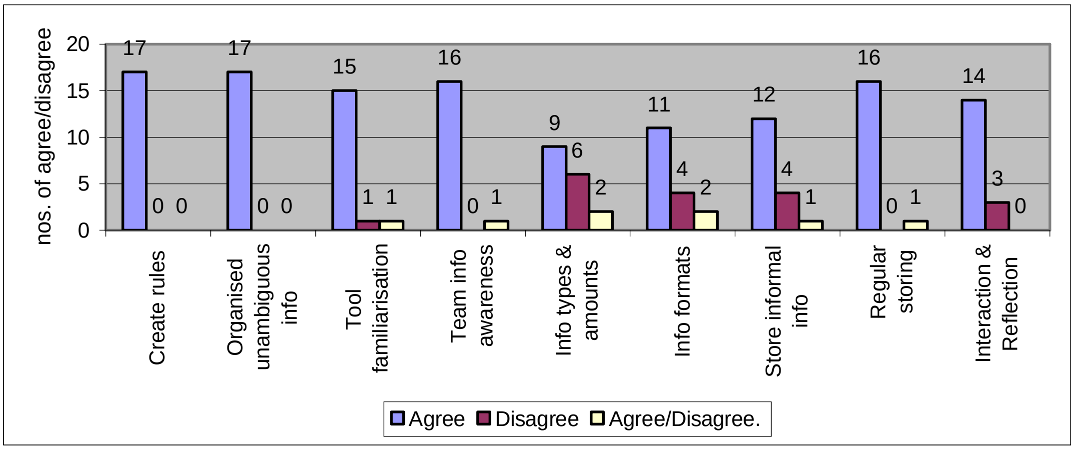


Figure 6.4: Student Focus Groups: Agreement/disagreement with Principles

All in Agreement

All students were in agreement with –

Principle 1 - *the need for global team project information strategy (creation of rules) early on*; and

Principle 2 - *storing of organised, comprehensive and unambiguous project information.*

They noted that without a strategy for storing and sharing information, information could be lost or duplicated; be inappropriate or untimely. Time could be wasted; quality of project information could be affected; resulting in a lack of project direction, confusion and disagreement. Several students came to this conclusion having experienced the disadvantage of not having a clear information strategy for the storing and sharing of information in the Global Design Project. –

> *"We had situations where overlapping of work happened – wasted time/resources, due to misdirection and no formal rules…who should do what, when and how?* (FG2.3)

Students reported that organised information helped to give a clear understanding of project scope and reduced misinterpretation. Several participants also linked organised information to the ease of access/retrieval of project information; e.g.

> *"The organisation of information is the key to quick retrieval."* (FG2.5)

Majority Agreement

The majority of students were in agreement with –

Principle 3 - *selection and familiarisation of tool(s) before project start*;

Principle 4 - *team awareness of where information is stored*; with

Principle 8 - *regular storing of project information throughout project by both sides of distributed team*; and with

Principle 9 *– interaction and reflection with stored information*.

Most students felt that tool selection and familiarisation was important - *"Absolutely vital to ensure maximum efficiency of team working."* (FG2.1) One student '*disagreed'* noting that any information strategy must allow for flexibility and integration of new tools during project work should the need arise. Another student '*agreed/disagreed'*, noting that students have limited knowledge of information storing tools and could perhaps choose the wrong tool. This indeed could be the case. To mitigate against this, in the Global Design Projects, the teaching team selected and allocated pre-tested and appropriate tools to teams, or offered a range of tools for the students to choose from. A short period of time was also set aside at the beginning of the projects to become familiar with the tools.

Whilst all participants *'agreed'* with ***Principle 4*** *– awareness of where information is stored*, (with one participant *'agreeing'* and *'disagreeing'*), students noted that it was not always the case that everyone knew where information was. Often one person on each side of a distributed team was responsible for storing 'local' information to the shared workspace. Students noted they found it difficult to keep track of information due to the large number of technologies available to exchange information and the ease with which copies could be made, often creating versioning issues. Students reported that knowing where information was stored saved time; aided the team in efficiency of data retrieval; reduced frustration in having to search everywhere for information; reduced delays in the design process; promoted data integration and global understanding.

They found that frequent and regular storing of project information helped to keep team members up-to-date and to track progress, however this was not always put into practice. One student reported that there was the tendency to upload information towards the end of a project in a 'rush' and that this must be discouraged. Others agreed. Sporadic storing can impact on team cohesion – *"Demoralised if the other side only makes sporadic contributions."* (FG1.7) One of the participants both *'agreed'* and *'disagreed'* suggesting that storing information on a regular basis might result in the storing of redundant information, which was not desirable. Information should be stored consistently throughout a distributed project when there is a genuine need.

Although students acknowledged that it was good practice to reflect on and interact with stored information, this was not always practised. Three of the seventeen students even *'disagreed'* with the Principle to encourage *interaction and reflection* with stored project information. One of these students reported reflection was less important. Nevertheless the view held here is that making both interaction and reflection the focus for a Principle should help to emphasis their importance to students. In support of this educators must increase the opportunities to engage in these processes through class and project design.

Greatest variance

Principles 5, 6 and 7 afforded most variance and discussion. The fewest number of students agreed with –

Principle 5 - *what information content to store and how much*, (9 students from 17). They felt that too much information contributed to loss of focus; storing unnecessary information wasted time; documents were often not referred back to. One student noted: *"Managing information includes disposal of information"*. (FG2.4) Disagreeing students believed that restrictions on what to store would result in limitations, e.g. lack of ideas, loss of information. Students considered storage space to be inexpensive and the amount of information to be stored was only limited by size of storage space. However evidence indicates that storing everything exacerbates the issues associated with distributed design information storing. Good information management practices provide students with guidance on what to store.

Six students from seventeen did not agree with –

Principle 6 - *what information formats to store.* Confusion over the terminology used here - '*formats*' being taken to mean '*file formats*' rather than '*information carriers'* or '*media type*' - affected the results. There was agreement that all useful information should be capable of being stored and that some systems currently prevent this. Principles 5 & 6 were found to be similar and they suggested these be merged.

There was also some disagreement with –

Principle 7 *- storing of informal information to add richness and understanding* (5 students from 17). Students reported they often found informal information hard to articulate preferring face-to-face interaction to understand context better. This is often not possible in distributed situations, particularly in asynchronous situations. There also seemed to be some concern about keeping information 'professional' and informal information was perceived, by some students, to clutter the storage space. In several cases students were not exactly sure what constituted informal information but recognised that "*Informal information helps team closeness*." (FG1.2)

Gaps

The second part of the Focus Groups involved students, in groups of three, identifying gaps in the Principles and discussing the Framework. Students suggested for example, privacy of information; times for reflection and feedback; integration with communication tools; and definition of informal information; were missing. They also offered up good practice, for example, a requirement for versioning; storing of profile information to increase team cohesion; simplicity of systems used; summary descriptions of information types and use of file naming conventions.

Feedback on Framework

In their groups of three, students were asked to give written feedback. There was strong support for a visual model. Students reported that the numbering system should be re-ordered. There was a recognition that the activities around the stored information, (organising; being aware of where information was; regularly storing; interacting on and reflecting with information) should be undertaken throughout distributed project work. Students found Principles 5 (*what information content to store and how much*) and 6 very similar and suggested they be merged. More guidance and advice was needed to support Principle 5. There was also a desire for the Framework to show the distinction between storing of formal and informal information content and the need to link these types of information.

Open Discussion at Student Focus Groups

The third part of the Focus Groups involved an open discussion with the participants of each focus group; prompted by author composed semi-structured questions. There was consensus that the Principles were very useful but perhaps too general. More specific advice was needed and it was suggested by both focus groups that their relevance in practice be made explicit through the use of examples, in particular what might happen if good practice principles were not applied. The principles needed to become part of class/project design and staff must place emphasis on them when teaching. One student suggested a form of list for good distributed information storing practice. They felt this would encourage reflection throughout the project. Other students felt it best to introduce the principles at the beginning of the project in a seminar. Quality of information was important to students –

> *"…it's not good to store huge amounts of information that nobody is going to go back to …that is like completely useless…to know that it will be important in the future, and it's got a purpose."* (FG1.3)

They reported that lack of time contributed to poorly distributed information management. Supporting this, they noted Principles 1 & 3 as the most important - the need for *a project information strategy* and *familiarisation with tool(s)*.
Students' views varied on what and how much information should be stored. Some students felt it was counterproductive to store all information, reporting that only key information should be stored: formal information to support the project objectives. Others felt that all information was vital, although this took time to store. There was recognition of the need and value of informal information for reflection but students couldn't agree on how much of this to store. Informal information was perceived as long and messy, 'cluttering up' the system by several students.

6.4.3 Refinement of Principles

The Principles were refined based on student feedback at the Focus Groups, see Table 6.5. Key changes included –

- the merging of Principles 5 & 6, as they were too similar;
- adding a new Principle on a '*comprehensive picture*' of the project;
- re-numbering and re-ordering of the Principles on the Framework;

- using different terminology for clearer meaning and understanding;
- the development of additional guidance from the recommendations to support, in particular, what information to store, how much and informal information.

	Good practice -
1	Emphasises the need for a distributed team project information strategy.
2	Requires selection of tool(s) and acquiring of knowledge of their use before project start.
3	Involves storing appropriate information: content, media types and amount of information relative to project.
4	Encourages richness of information by storing informal information in addition to formal information.
5	Requires project information to be unambiguous, structured and organised.
6	Supports a shared team awareness of where distributed design information lies.
7	Emphasises the regular storing of information throughout project by all members of distributed team.
8	Provides opportunities for interaction with and reflection on stored distributed design information throughout project.
9	Records and communicates a comprehensive picture of project challenges, processes, rationale and outcomes.

Table 6.5: Refined Principles following Student Focus Groups

6.4.4 Staff Focus Groups

Staff were mainly in *'agreement'* with the Principles (see Figure 6.5) with strong similarities across the two Staff Focus Groups. Staff *'disagreed'* most on the same two Principles (see Appendix 6.4) -

- unambiguous, structured and organised project information, and
- the regular storing of information by all members of the distributed team.

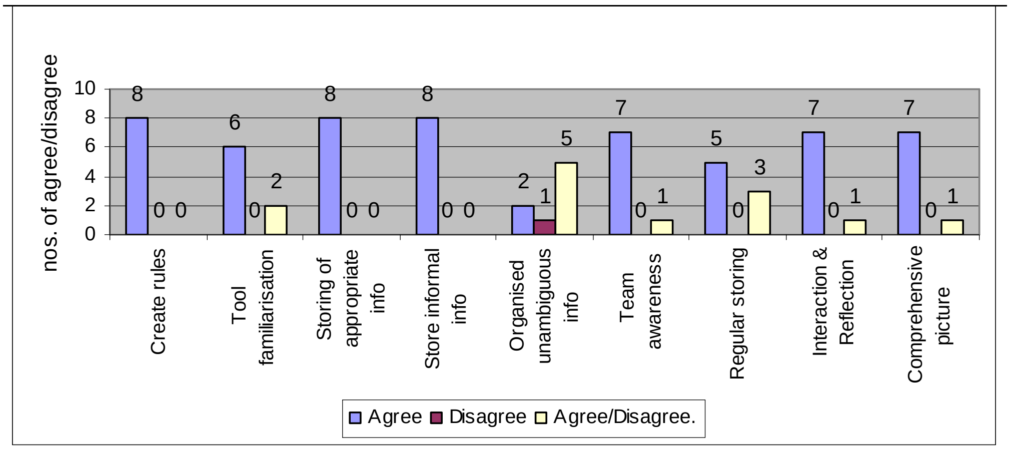


Figure 6.5: Staff Focus Group: Agreement/disagreement with Principles

All in Agreement

Like the students, all staff agreed on having an information strategy and creating rules. They noted that without these, things could become very chaotic, compounded further in a distributed design situation. In the staff's experience students tended not to think about how information might be stored. By developing a set of Principles, focusing on key aspects of distributed-design information storing, students can be made more aware of the importance of initiating a strategy pre-project. Staff also felt that any strategy should be capable of being amended and flexible to some extent, during a project.

All staff *'agreed'* with the Principle on *storing appropriate information content, information carriers* and *amount of information relative to project*, however, they noted that the indeterminate nature of design and the complexity of each project and team made this difficult to do. The early case studies, however suggest that equal amounts of formal and informal information would be a good position to start, as storing only formal project documentation leads to an incomplete picture and partial project (hi)story. Staff felt that giving prior consideration to what was 'appropriate' information to store could avoid information overload and, also information under load.

They also all agreed with the Principle on the *storing of informal information in addition to formal information to add richness*. One researcher noted this was an important Principle and critical to understanding. (FG4.1) Formal information alone was not sufficient for accurate project records. The meaning of formal information could be lost if not supported by informal information (Huet, 2006; Conway et al., 2008).

Majority Agreement

Staff strongly supported the Principles on -

- *team awareness of where information lies;*
- *interaction and reflection;* and
- the new principle on *recording of a comprehensive picture of the project.*

If everyone was aware of where information was, then they were more likely to use the same information, avoiding confusion and inconsistent decisions based on different information. They agreed that a simple information management system or the structuring of information would support awareness of where information lay, which would then facilitate cohesive team working; reduce time wasted finding information or even prevent the use of '*inappropriate*' closest matched information.

Staff reported that reflection was essential and that it is critical that information is not simply stored and forgotten about. From experience academics noted that getting students to reflect was difficult, but desirable. This required planning on the part of the educator –

> *"Critical for project reflection and analysis of strengths and weaknesses of project, i.e. what could be done better next time. Important for 'new' teams who may want to learn from lessons of others or for class tutors to identify guidelines for new projects".* (FG3.3)

One academic suggested that more guidance was needed to advise students on what information and how much would constitute *a comprehensive picture*, as students found this difficult to evaluate. Staff felt how well the information storing recorded a complete picture would depend on the level of information captured; the type and structure for retrieval.

Most staff agreed (6 of 8) that students should select tools to store information and know how to use them prior to project start. One academic noted that information literacy literature supports this principle (Bruce, 1997). However, a few academics, did not agree that the team had to know how to use the technologies before project start, as learning technologies *'on the job'* was not uncommon, particularly in industry. Staff felt that there should be a core of tools available to allow for flexibility and adaptability, and not to hamper creativity, with the ability for others to be added later if required.

Greatest variance

The greatest variance in agreement amongst academics and research staff came about as a result of the terminology used in some of the Principles. The greatest disagreement was over the term '*regular'*. Those that *'agreed'* noted that for effective shared information storage all team members must contribute throughout the project; modifying their usual behaviour if needed. This could prove difficult for students as they typically store information at the end of a project or at predetermined milestones. Academics can change this behaviour through revised project or class design. One academic noted that patterns of design activity (and this includes information storing) evolve naturally during project work and enforcing a '*regular'* storing of information could interfere with this and possibly hamper creativity on a project. (FG3.3) Staff continued to debate over the term, finally preferring to use the term '*consistent'* or *'frequent'* instead. Staff recognised the importance of organised and structured information, however, most were uncomfortable with the use of the term '*unambiguous*', which could easily be misunderstood by students. They agreed that the word '*clarity'* would be better suited.

Only one member of staff *'disagreed'* with any of the Principles – the Principle of *unambiguous, organised and structured information.* (FG4.4) He argued that design information is often ambiguous, uncertain, unstructured and disorganised, and that it needs to be recorded in its original form. However, the information should be presented in such a way that the information user is aware of these factors and can still understand its meaning. The author agrees with this. In the thesis, and the Principles, the terms *'organised'* ,*'structured'* and *'unambiguous'* refer to the manner of storing and not to the actual information content itself. All information, in all states, including any ambiguous information, should be stored in an organised or structured manner to allow for easy retrieval.

Gaps

Staff gave feedback on gaps and the Framework in pairs. Gaps included the need for flexibility to be built into any strategy to allow for changes or problems as they arose. There was a suggestion that guidance on information capture and retrieval was missing. (FG3.2, FG3.4) This was not a thesis focus although the earlier Case Studies describe and discuss several methods used by the distributed teams to capture and share project information. Another researcher suggested that the aspect of a shared awareness of the quality or value of the information might be missing. (FG4.4)

Feedback on Framework

In their pairs, the staff made comments on the Principles Framework. It was suggested that the central *Project Memory* could assist with future projects' information re-use, and that an arrow be drawn from the *project archive* back to the pre-project stage. Developing the Principles to help manage distributed design information storing was the key aim of the thesis work, but also having a *Project Memory* for re-use as learning resource material, in both distributed project work and other educational contexts, is a valuable opportunity for academics and researchers. Some staff felt numbering and ordering of the Principles was not necessary. The Principles appeared unique and independent as presented. Another researcher (expert in the area of information management) noted that the Information Storing Framework made good sense of the Principles. (FG4.2)

Open discussion at Staff Focus Groups

Staff considered the Principles to be useful; something practical students could implement in project work and also be of use to academics in class design. They felt the Principles should be kept broad and not be too specific so they could be used in different classes and even across disciplines. A number of academics reiterated that students might find it difficult to interpret the Principles and apply them in their project work in reality, without further additional supporting advice. In order to make the Principles more acceptable by students certain terminology would have to be changed to avoid misunderstanding, for example, *'formats', 'regular', 'unambiguous'*. And finally, they thought the Principles would improve performance by providing a structure in themselves. They could be seen as a 'kick-start' to information storing in distributed project work. In terms of implementing the Principles in the class, academics and researchers agreed with the students' suggestions for previous examples of storing, good and bad; a list for use throughout project work; and also more time given to project planning. In particular, academics felt it was important to get students to reflect on the storing of their structured information.

6.5 Further Discussion

The Principles evolved from a need from the literature; an existing gap in the provision of guidance on engineering information management, in particular information storing, and from the issues discovered in the Case Studies. The feedback from Focus Groups with students and academic and research staff has also shown a strong need for a set of guiding Principles for distributed-design information storing.

Results across the two Student Focus Groups compared favourably and likewise across the two Staff Focus Groups which helped to add credibility to the feedback offered by the participants (Guba & Lincoln, 1981). One focus group for students and one for staff would not have provided sufficient response to establish any credibility (Bryman, 2004). However the students' groups and the staff groups did not necessarily share the same views and concerns; both of which have been addressed in the final development of the Principles. Whilst all were unanimous in agreement that the Principles would support a strategy and that information should be organised and structured, the students still considered more guidance was needed on what type of information to store and how much. The academics and the researchers were more concerned with the terminologies used, so as not to confuse students. The students showed little difficulty in understanding the Principles and the terms used however several had to have *'Informal information'* described for them at the Focus Groups. A glossary of terms is vital to include in students' instruction. A number of academics also reiterated that students would find it difficult to interpret the Principles and apply them in their project work in reality, without the support of facilitating academics during project work.

Student and staff feedback at this stage was instrumental in the development of the Principles, providing key and critical advice on the author's interpretation of, and response to, the issues presented by the Case Studies. The Focus Groups can be regarded as a vehicle for *action research* where the user groups, the students and staff, and the author were all contributing to the development of the Principles and Framework, intended to bring about a transformation and improvement in student information handling behaviours. Students and staff freely contributed towards this development of the Principles and Framework at the Focus Groups. The results of the Focus Groups were used to develop the final version which will be presented in the next Section.

6.6 The Final 9 Principles for Distributed Design Information Storing

Key revisions and improvements, suggested by the students and staff, at the Focus Groups, included –

- the use of alternative terminology for bettering understanding;
- the removal of any numbering system;
- the addition of a number of guidance points (in the *Principles Guidance Document*; see Appendix 6.5) to support some Principles as not enough advice had originally been given; and
- the raising of importance of one principle to an ***Overarching Principle*** – the ***Principle of Strategy***. Adoption of the nine key principles, designed to improve good practice, supports the Overarching Principle of Strategy - the need for a distributed team project information storing strategy.

See Table 6.6 and Figure 6.6 for the final version of the Principles; and Figure 6.7 for the final version of the Framework.

Overarching Principle	Develop a distributed team project information storing strategy early on in distributed project work.
Principle of System Support	Select tool(s) and familiarise with use before project start.
Principle of Information Type	Store an appropriate range of information types: content (formal and informal), state, media and format, relevant to project.
Principle of Quantity & Size	Store an appropriate amount of information relative to project task and time.
Principle of Context and Clarity	Store informal information to add shared meaning and understanding to formal information in a distributed situation.
Principle of Structure	Structure and organise distributed design information.
Principle of Location & Retrieval	Be aware of where distributed design information lies.
Principle of Consistency	Store distributed design information consistently throughout project by all members of distributed team.
Principle of Interaction & Reflection	Interact with and reflect on stored distributed design information throughout the project.
Principle of Memory	Record and communicate a comprehensive memory of project problems, processes, rationale and outcomes.

Table 6.6: The 9 Principles distributed-Design Information Storing - Final Version

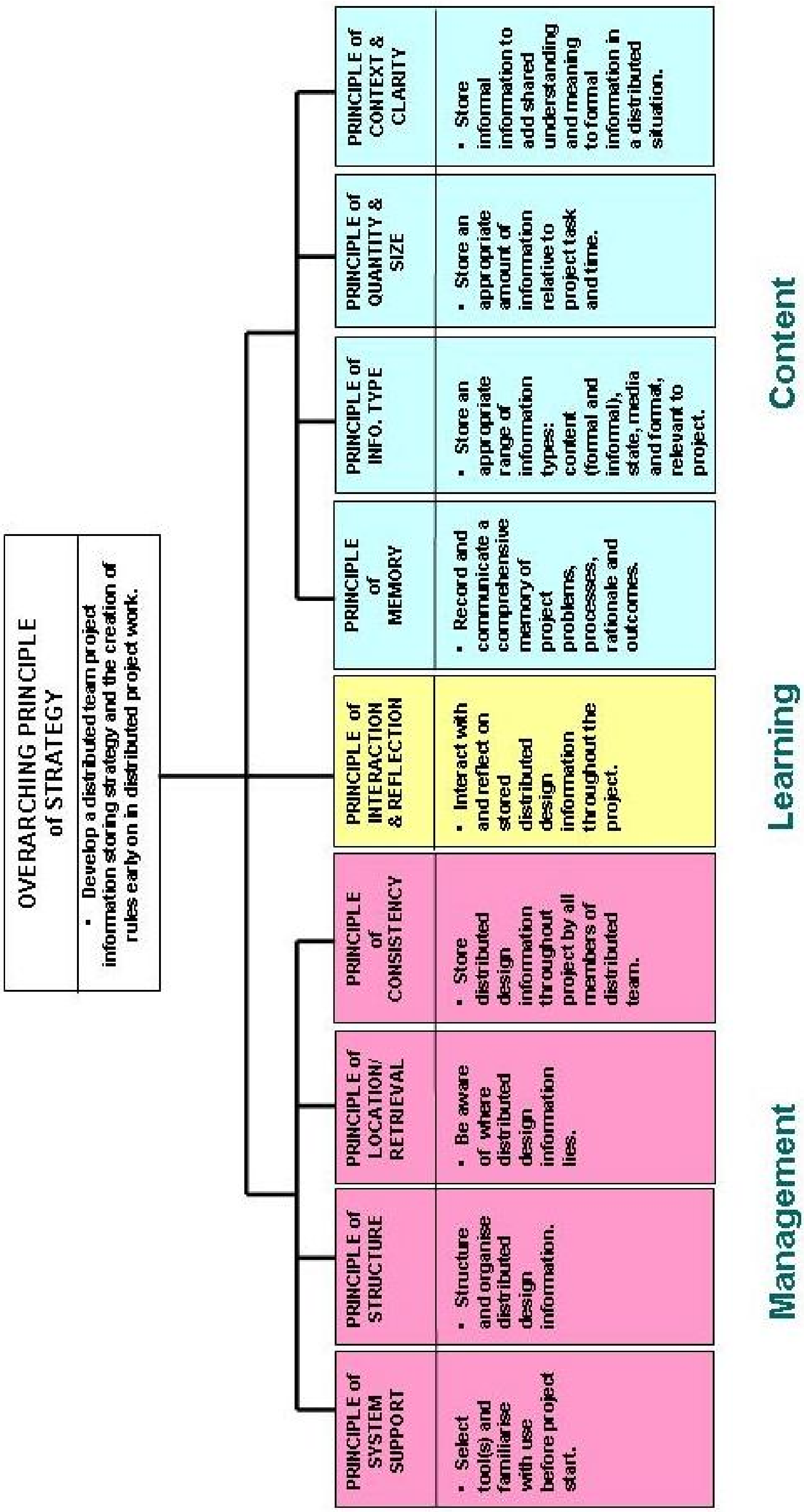


Figure 6.6: The 9 Principles of distributed-Design Information Storing

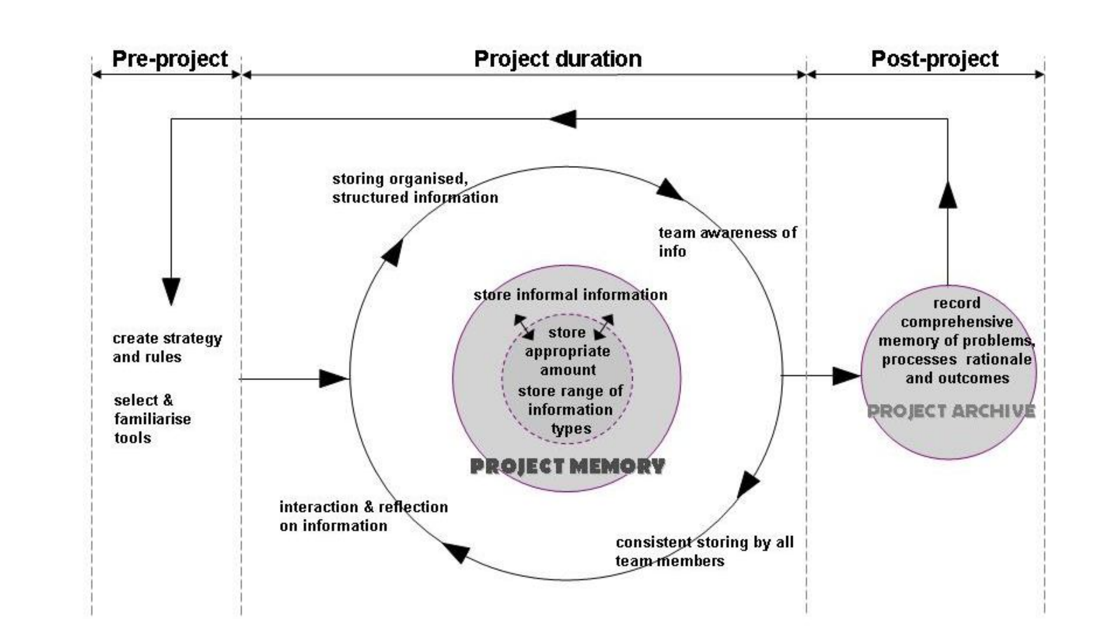


Figure 6.7: The distributed-Design Information Storing Framework - Final Version

For greatest impact, global teams should develop an overall strategy which involves considering all the Principles at the start of the project and then applying the 9 Principles for d-DIS *'throughout'* distributed project work. This supports the management and sharing of distributed information; interaction and reflection with the stored information and improved distributed information storing skills.

Current work of others also helped to shape the Principles at this point, for example, a set of Principles of Engineering Information Management from the KIM Project (McMahon et al., 2009). A similar presentation model to the KIM Project Principles has been adopted for the presentation of these Principles. Chosen for its simplicity it is ideal for educational and instructional purposes. The model comprises –

1. top level Principles, each supported by,
2. an explanation (See Table 6.7), and
3. further guidance for each Principle.

Presented in this manner each principle will have its own name and be readily identifiable to students. This also helps to give each principle independence. The explanations of each Principle make their purpose clear; and importantly the additional guidance and advice in the *Principles Guidance Document* (see Appendix 6.5) further supports good practice.

Overarching Principle

PRINCIPLE of STRATEGY

Develop a distributed team project information storing strategy and the creation of rules early on in project work.

Explanation: *Distributed design team work, by its very nature, requires a strategy to manage the storing of information to an even greater extent than traditional design. A strategy and rules are fundamental to co-ordinating the use of information and critical to the efficiency and effectiveness with which a team can share information. Without a clear strategy for storing and sharing information, information can be lost or duplicated, be inappropriate or untimely; and the quality of project information can be affected, resulting in a lack of project direction; time wasting; confusion and disagreement.*

PRINCIPLE of SYSTEM SUPPORT

Select tool(s) and familiarise with use before project start.

Explanation: *Distributed design information storing is best supported by a centralised shared electronic store. Satisfaction with information storing and sharing in distributed project work is often directly related to the technologies used. Selecting the best tool(s) based on information needs, project length and team requirements and becoming familiar with at least basic functionality saves time and benefits project progress most.*

PRINCIPLE of INFORMATION TYPE

Store an appropriate range of information types: content (formal and informal), state, media and format, relevant to project.

Explanation: *Storing a range of information types with both formal and informal content; in a range of states (e.g. raw, developed or finalised) using a variety of media and formats, in a 'Project Memory' (an online store of information and knowledge gathered and generated during a project) helps give meaning and understanding to all project information and progresses project work.*

PRINCIPLE of QUANTITY and SIZE

Store an appropriate amount of information relative to project task and time.

Explanation: *Each project is different and unique and, it is important to consider how much information to store depending on the length of the project, the scope of the task, and the number of team members* **-** *not too much and not too little.*

PRINCIPLE of CONTEXT and CLARITY

Store informal information to add shared meaning and understanding to formal information in a distributed situation.

Explanation: *In distributed design there is a need for context. Informal information can add meaning and context. A shared understanding and meaning of formal information can be promoted in a distributed situation through the storing of more informal information. There is also a greater need for making information clear in distributed design work due to the lack of opportunities for explanation and discussion. Teams are more efficient and productive when information is understandable.*

PRINCIPLE of STRUCTURE   **Structure and organise distributed design information.**   ***Explanation:*** *If consideration is given to the structuring and organising of distributed design information early on in project work, information storing, sharing and retrieval will be easier and less time-consuming.*
PRINCIPLE of LOCATION/RETRIEVAL   **Be aware of where distributed design information is stored.**   ***Explanation:*** *Distributed design information needs to be found easily and quickly. It is important that each team member knows where distributed design information is stored at any given time. This means the team is more likely to use the same information; avoid confusion; reduce inconsistent decisions based on different information; and save time which could be best spent on other design activities.*
PRINCIPLE of CONSISTENCY   **Store distributed design information throughout project by all members of distributed team.**   ***Explanation:*** *For information to be most effective during a distributed design project it needs to be shared and available to all team members at the time of information need. Information recorded sporadically can disadvantage a team and impact negatively on team cohesion.*
PRINCIPLE of INTERACTION & REFLECTION   **Interact with and reflection on stored distributed design information throughout the project.**   ***Explanation:*** *Interaction with information keeps team members updated during a project; helps them visualise what others in team are doing and promotes a feeling of collaboration. Maintaining an online store of project information or a 'Project Memory' is critical for project reflection, for future learning, and informing what can be improved the next time.*
PRINCIPLE of MEMORY   **Record and communicate a comprehensive memory of project problems, processes, rationale and outcomes.**   ***Explanation:*** *Project information storing creates a project archive which can be used to recall the story of the project at a later date. The information can be re-used for the purposes of assessment; reflective reporting; examinations; class discussion; for exemplars, and even for learning from failures.*

Table 6.7: Principles for d-DIS with 'Explanations'

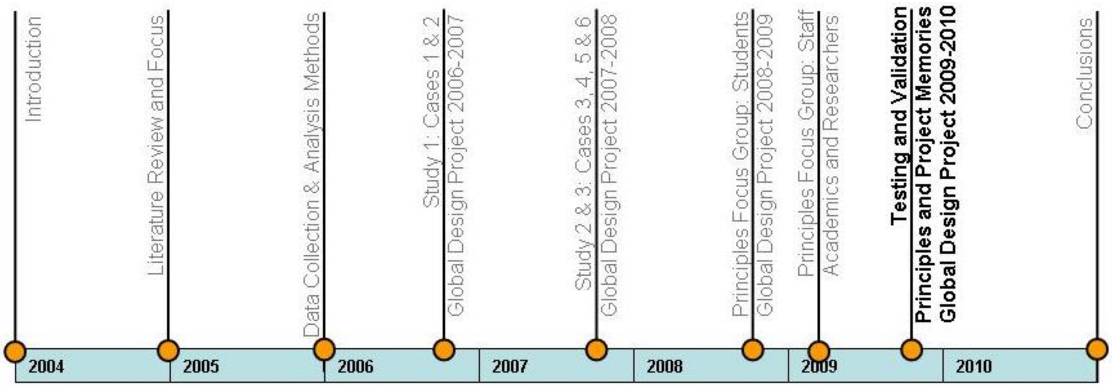
6.7 Summary

This Chapter started by making the case for Principles based on the findings of the descriptive Case Studies and subsequent Recommendations for distributed design information storing. Principles have been used widely in education as a method of support and guidance. They are extremely versatile in their implementation and use, and as such, suit a wide range of applications. More recently they are being used in industry and practice as highlighted by the work of the KIM Grand Challenge Project; and in education, for example Nicol and Mcfarlane-Dick's (2006) Principles for Assessment and Self-Regulated Learning.

The development of the Principles is covered in this Chapter, with particular emphasis on the student and staff contribution to their development and refinement through a number of Focus Groups. Feedback on the Principles for d-DIS and the Principles Framework was positive: students and staff considered the Principles would help reduce the frustration and confusion often associated with distributed project work, e.g. lost and incomplete information, lack of context, poor communication, unable to find information, lack of team trust, etc. Students reported that implementing the Principles would certainly save time; support better collaboration and help them to manage and share project resources better; all allowing more focus on the design challenge set before them. Students also expressed a need to have examples to understand the importance of the Principles and their relevance. The participating Staff at two Focus Groups, were in favour of the use of the Principles as their implementation would provide a valuable archive which could support project reflection and offer opportunities for learning. Additionally their implementation would promote good practice in distributed design information storing and better prepare students for industry and employment in the global market.

Chapter 7 now reports and discusses the validation of the developed Principles for distributed-Design Information Storing, in the 2009-2010 Global Design Project.

7 Validation of Principles & Project Memory



7.1 Introduction

This Chapter will focus on the final stage of the work – *Description II*; validation and testing. It is set in two parts: the implementation, testing and validation of the proposed set of guiding Principles, and the examination of the content of a Project Memory of a distributed team following the use and consideration of the Principles on a Global Design Project.

Part 1: Implementation and Validation of Principles

This section will begin by describing how the Principles can be applied by both educators and students; illustrated by their use in the 2009-2010 Global Design Project, by seven global teams. The Chapter will then outline the Validation Methodology used and present the student feedback on the use of the Principles in improving distributed-design information storing practices.

7.2 Educators' Use of Principles

As described before in Chapter 6, one of the pedagogical values of principles lies in their flexibility and broadness of implementation, making them suitable for a wide range of applications across many disciplines, whilst at the same time adaptable to suit individual situations. In the case of this work, educators can implement all the principles in the development of project work or activities, or simply a few principles at a time for the easier identification of the impact particular principles might have on a distributed design information storing process.

7.2.1 A Series of Questions

To facilitate educators' use of the Principles a series of simple questions (which will be referred to as the *Educators' Principles Questions*) has been developed to support each Principle, See Table 7.1, overleaf. This practice has been adopted by Nicol and Mcfarlane-Dick (2006) in their Principles for Assessment and Self-regulated Learning. The questions can be used by educators initially to evaluate to what extent project work or project activities allow for good distributed information storing practices. Reference to the full *Principles for d-DIS Guidance Document* (Appendix 6.5) can then be made for further support and guidance.

7.2.2 Revising the Global Design Project

Using the series of questions in the *Educators' Principles* the author assessed previous Global Design Projects and identified areas for change. The explicit use of the *Educators' Principles*, by responding to the series of questions for each Principle, was important in influencing the new project structure. See Appendix 7.1 for the *Educators' Principles* used to identify changes to the 2009-2010 Global Design Project and the changes made in order to implement the Principles.

It was crucial that the focus of the Global Design Project remained on distributed design rather than distributed-design information management so interventions were kept to a fairly low level. This allowed teams to exercise flexibility in their use and freedom in their application. It was also anticipated that 5th year and Postgraduate students should possess the maturity to work with the Principles independently, taking a 'self-managed' approach. Changes to the 2009-2010 Global Design Project included –

- increased lead-in time to the Global Design Project (one full week);
- a more-tasked based approach to project working ensuring students knew what was expected of them;
- selection of technologies by teaching staff (simper and easier to use systems);
- introductory presentation on the Principles;
- provision of material for students on Principles (the *Principles, Framework* and the *Principles for d-DIS Guidance Document*) for use before and during distributed project work;

- greater emphasis on distributed information storing and sharing by teaching staff during the project; and
- opportunity to reflect on information storing processes at end of the project.

Good distributed information storing practice should:	
OP	**Emphasise the need for a distributed team project information storing strategy early on in distributed project work.** *To what extent do project activities allow for the development of an information strategy before project start?*
1.	**Encourage the selection of tool(s) and familiarisation of use before project start.** *To what extent can student teams select tool(s) for storing project resources and is time allocated for familiarising themselves with the tools pre-project?*
2.	**Require the storing of an appropriate range of information types: content (formal and informal), state, media and format, relevant to project.** *What formal opportunities are offered to student teams to determine and assess information content, state, media type or formats throughout project work? What guidance is given to students on what and how to store project information?*
3.	**Encourage storing an appropriate amount of information relative to project task and time.** *What formal opportunities are offered to student teams to determine and assess how much information to store? What guidance is given to students on how much project information to store?*
4.	**Encourage the storing of informal information to add shared meaning and understanding of formal information in a distributed situation.** *To what extent are student teams encouraged to record the more informal aspect of their work, e.g. project process and design rationale?*
5.	**Encourage the structuring and organising of distributed design information.** *To what extent do project activities encourage the structuring and organising of distributed design information?*
6.	**Encourage an awareness of where distributed design information lies.** *To what extent do project activities support student team communication of project resources and information?*
7.	**Emphasise the consistent storing of distributed design information throughout project by all members of distributed team.** *To what extent do project activities encourage the consistent storing of project information by every student?*
8.	**Provide opportunities for interaction with and reflection on stored distributed design information throughout the project.** *What formal opportunities are there in project design and project activities for interaction with stored project information? To what extent are there formal opportunities for students to reflect on project resources?*
9.	**Record and communicate a comprehensive memory of project problems, processes, rationale and outcomes.** *To what extent do project activities help to build a comprehensive story of project development and outcomes?*

Table 7.1: Educators' Principles (Questions)

7.3 Implementation of Principles in Global Design Project Work

The Principles for d-DIS were first used by Product Design Engineering students from Strathclyde (UK) and Swinburne (Australia) Universities on the asynchronous 2009-2010 Global Design Project. The project task was the same as previous years - the design of a coffee cup holder. The format was the same, except for the revisions made to the project as outlined in Section 7.2.2. Three web-based tools, suitable for storing project information, were selected by teaching staff based on previous student recommendation for their simplicity of use – *Google Docs, Wetpaint* and *Blogger*[17]. Each team was assigned a tool and the students were instructed to use the Principles early on and to reflect on their team distributed information management from time to time during project work.

7.3.1 Principles as an Intervention

The implementation of the Principles was kept low key. It was anticipated that since the Principles were able to be used with a high degree of flexibility and since the students involved were final year and postgraduate students that a self-managed approach would be taken. Implementation included a presentation and the issuing of the Principles in material form which could be used during project work. The impact of the Principles intervention will be covered at the end of this Chapter.

7.3.2 Presentation of Principles

The Principles were introduced in an hour long presentation to all Strathclyde students at the beginning of the pre-project week. Swinburne staff gave the same presentation to the Swinburne students. The presentation summarised and covered the following –

- the issues associated with distributed-design information storing (drawn from the earlier case studies);
- the derivation and explanation of the Principles and the Framework and rationale for their use;
- examples of past student distributed-design information storing experiences; and

[17] Blogger - is a blog storage service that allows private or multi-user blogs with time-stamped entries.

- general broad instructions to use the Principles to consider a distributed information strategy and reflect on information storing practices.

7.3.3 Student Material

Each side of the global teams were issued with physical copies of –

1. the *Principles* and *Framework* (see Appendix 7.2) to use to discuss and monitor their global team information storing practices during the project; and,
2. the *Principles for d-DIS Guidance Document* (see Appendix 6.5).

Students were requested to keep this documentation confidential, for use only within the context of the Global Design Project.

7.4 Validation Methodology

The validation of design methods and tools is a difficult area of research, due mainly to the large number of factors affecting design processes at any one time (Blessing, 1998). A further evaluation difficulty, for this work, lay in the inability to have a ‘control group’. The context for implementation was a ‘real’ class taken for credit and as such no student could be advantaged or disadvantaged. Both qualitative and (to a lesser extent) quantitative research methods have been used to evaluate the Principles and Framework and *Project Memory* information content. See Appendix 7.3 for the Evaluation Plan. The two key elements of this *Description Stage II/Validation* included –

1. ***Student Validation of the Principles***: to establish the extent to which the *Prescription* (the Principles) has the expected effect on the distributed-design information storing issues identified at the earlier *Descriptive Stage I*. Validation methods include the use of a **Questionnaire** and a **Focus Group**. The results are presented in this Chapter.
2. ***Case study comparison:*** to determine whether the application of the *Prescription* contributed to a successful *Project Memory*. Validation methods included the **Data/Document Analysis** of one online project site, followed by a **Semi-structured Interview**. These results will be presented in Chapter 8.

See Appendix 7.4 for the research methods used in Validation and information on the data sets. The methods used in the Validation were the same as those used in earlier descriptive studies as described in Chapters 3; details will be outlined below.

7.4.1 Questionnaire

All Strathclyde sides to global teams were invited to complete a questionnaire as part of a reflective session in class. All Strathclyde sides completed the questionnaire (eleven in total). All Swinburne sides of the teams were emailed the same questionnaire. Seven completed scanned questionnaires were returned. These seven questionnaires and the questionnaires from their corresponding Strathclyde local sides made up the data set used in this part of the validation (fourteen questionnaires). See Table 7.2 for the questions and the style of responses and see Appendix 7.5 for an example of a questionnaire.

Questions for local sides to teams		Style of Response
1	For each of the Principles note how your team considered and implemented each Principle to support distributed-design information storing.	open-ended
2	When was each Principle acted on?	tick-box (scale – never, early on, mid project, all throughout, at end)
3	How effective was each Principle?	tick-box (Likert scale – 1-5; least effective to most effective)
4	16 closed structured questions relating directly to the aims of the Principles and their improvement of information storing in distributed project work.	survey style (scale – strongly agree; agree; neither agree/ nor disagree; disagree; strongly disagree)

Table 7.2: Questions and Response Styles in Questionnaire

The survey-style questions afforded measures relating to the issues identified in distributed-design information storing, against the aims of the Principles. Relating the *Description II/Validation Stage* of Blessing's Model to the *Description* and *Prescription Stages* is beneficial (Blessing et al., 1998).

Questionnaire responses were analysed, clarified and validated with f2f (real-time) Strathclyde student interviews and emails to the Swinburne students. Limitations need noting. Firstly, the Swinburne students graduated shortly after taking part in the Global Design Project and despite several emails four of the seven teams (Teams A, B, E and I) either had no time to respond or did not respond to requests for clarification of responses. This resulted in 9 unchallenged responses from 942 possible responses, which was acceptable. Secondly, some 'negatively framed' closed statements were included in the questionnaire which is deemed good practice. Analysis of these responses, based on evidence elsewhere in the questionnaire, suggested that a few of these had been incorrectly answered. Follow up consultations altered three of seven of these responses, with a further five unable to be confirmed. The results of the Questionnaire can be found in Section 7.5 below.

7.4.2 Focus Group

A Focus Group was held following the analysis of the Questionnaire. See Appendix 7.6 for the Focus Group Plan. Similar consent to interview was sought from the participants as in the semi-structured interviews and the Principles Focus groups. The purpose of the Focus Group was to validate and expand upon the findings of the questionnaires. Feeding back the results and findings of an investigation to participants acts as a source of phenomenological validity in itself. (Bronfenbrenner, 1976) The session was recorded on voice recorder and transcribed. The results of the Focus Group can be found in Section 7.5 below.

7.4.3 Data/Document analysis and Semi-structured Interview

One team's PM was selected for examination in terms of *what information content was stored; where, when* and *how it was stored*. The same Content Analysis methods were used as in the earlier Case Studies. A Semi-structured Interview followed, to present and confirm the findings and gain further insight. The results are discussed in Chapter 8 on Project Memories.

7.5 Student Use of Principles - Validation Results and Discussion

Both Strathclyde and Swinburne students contributed to the Questionnaire responses; Strathclyde students participated in the Focus Group.

7.5.1 When the Principles were used

Variation on *when* the Principles were used by the teams was expected. However it was hoped that the results would fall predominantly within the ranges of '*early on'*, '*mid project'* and '*all throughout'*, i.e. between the 'dotted lines' of Figures 7.1 and

7.2. The majority of Principles were considered by teams at these times. This is to be encouraged in distributed project work. There were some exceptions. Occurrences of *'never'* and *'at the end'* were low – 11 local sides reported they *'never'* considered a Principle and only 2 local sides reported *'at the end'* which is reassuring. These will be discussed in Section 7.5.2.

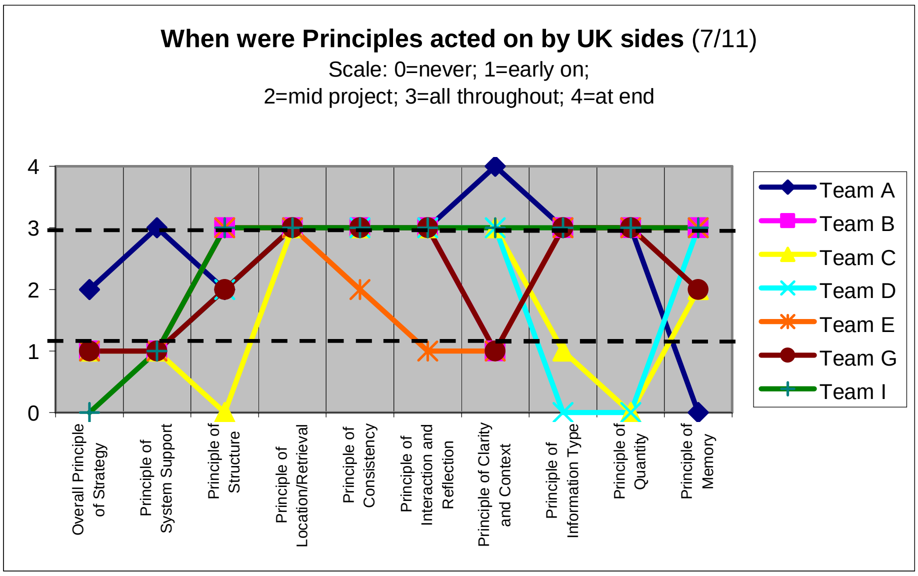


Figure 7.1: When Principles were acted on by Strathclyde sides

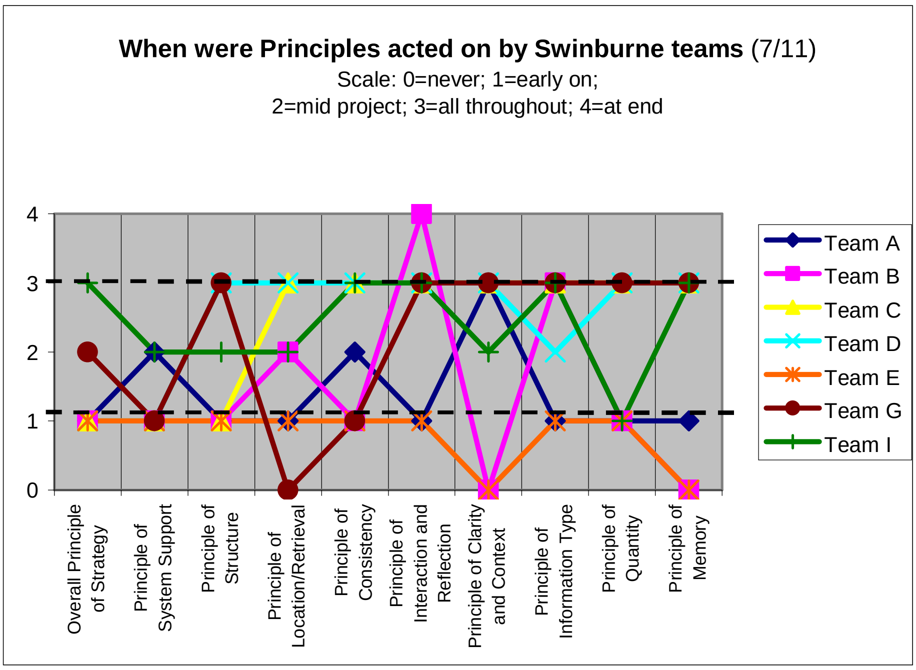


Figure 7.2: When Principles were acted on by Swinburne sides

Further examination of the line graphs shows there was also variation across local sides of the global teams, suggesting that the Principles had been used independently by local sides of global teams rather than jointly. This in itself is not problematic however it is important that the Overall Principle of Strategy is developed jointly to help strengthen team cohesion; increase ownership of project information by all and lay out 'ground rules' early on in distributed project work. Information flows and is shared more effectively when regarded as something belonging to the whole team (Ardichvil et al., 2003). Greater emphasis needs to be placed on the 'joint' aspect of this Principle.

Global teams should develop an Overall Strategy which involves considering all the Principles at the start of the project and then applying the 9 Principles for d-DIS *'all throughout'* for the greatest effect. This supports the management and sharing of distributed information; interaction and reflection with the stored information and improved distributed information storing skills. In future work the line graph, used to display the results of the use of the Principles in this study, could be used as a visual measure with the aim being to have more 'hits' along the top 'dotted line'.

7.5.2 Consideration of the Principles by Teams

Discussion of the findings are reported -

The Overall Principle of Strategy

This Principle was considered to be important to the students - *"Absolutely necessary."* (PFG3) It was considered by all teams either *'early on'*, *'mid project'* or *'all throughout'* except for Team I. For example, the Strathclyde side of Team I reported that since their tool (*Blogger*) was simple and straightforward to use, they *'never'* considered a formal strategy or plan for storing information. Whilst this is acceptable for a short project, where stored information may be limited, on longer projects as the amount of information increases, complexity and issues arise; strategies are integral to success. Team A did not introduce a strategy until they had problems '*mid project'*; experiencing lack of context issues and unclear information.

> *"…..once we started facing issues, it was more like damage control and getting it back on track so we decided we needed a strategy."* (PFG2)

Consideration and application of use of this Principle included -

- development of project plans and schedules to include communication, and uploading and updating of information (Teams B, C, E)
- use of various areas of tool(s) to support information storing (Teams A,D,E)
- creation of hierarchies for sharing information and classification of discussion threads (Team A)
- creation of folders (Team G)
- use of a communications tool alongside information storing tool, to discuss information (Teams D, E)

Team A recognised that an information strategy was dynamic; that it evolved and developed.

The Principle of System Support

During the first Case Studies students found the complexity of the technologies impacted on their information storing. There were very few complaints that tools were too complicated for purpose on the 2009-2010 Global Design Project. Students reported that both *Blogger* and *Google Docs* were easy to use and required little effort to learn.

The majority of the sides of teams considered and acted on this Principle *'early on'*, with some teams 'linking to' a communications tool to support their information storing tool, for example the use of *Google Groups* to support *Google Docs*. Without the Principles they noted they would not have considered this. All teams reported they were already familiar with or had familiarised themselves with the technologies before the project started and that this supported information storing, with the exception of one Swinburne side (Team B), who had never used *Wetpaint* and found it difficult to set up. They noted additional time to familiarise with the tool would have solved this. This Principle was found to reduce anxiety at the start of a project, *"… because as it is you have too many unknowns going into a project."* (PFG2)

The Principle of Structure

Structuring and organising distributed information is key to being able to find it. One team (Team G) reported they revised strategies when *Google Docs* introduced folders *'mid project'*. They found it more satisfactory to have control over organising and structuring. A variety of methods was used to structure and organise project information, although this was sometimes found to be limited by the simplicity of the technologies used. Reported applications of this *Principle of Structure* include –

- use of different web pages for information - homepage for updates (Team B); individual pages for each project stage (Team B), webpage options to cluster information (Teams A, B);
- storing of information chronologically (Teams C,D,I);
- creation of hierarchies for sharing information (Team A);
- use of folders (Team G).

The Principle of Structure was *'never'* considered by only one side (Strathclyde side of Team C (*Blogger*)). Their tool automatically archived information chronologically, a form of structuring in itself, however these students' preference was to organise the information themselves. In contrast Team I (also using *Blogger*) reported information organised chronologically on one wiki page was easy to find because they could remember when events happened throughout the project. However they recognised whilst this was ideal on a short project the need for more rigorous structuring and organising of information on a longer project was crucial.

The Principle of Location/Retrieval

All Strathclyde students considered this Principle *'all throughout'* distributed project work; with the Swinburne sides considering it more *'early on'*. Only one side of a team (Swinburne Team G) *'never'* considered the Principle of Location/Retrieval. (No response was received on follow-up.) Reported considerations in relation to this Principle include -

- information was more easily located with some notification or communication about the information itself,
- communication levels needed to be kept high,
- the use of a centralised shared workspace or information storing tool helped awareness of distributed-design information.

The Principle of Consistency

Students recognised the need for the consistent and frequent storing of distributed information. To them this Principle involved –

- the uploading or posting of information regularly (Teams A,B,C);

but they also understood this principle to consider other aspects of consistency, expanding the focus of this Principle –

- the naming of files appropriately (Teams A,D); the use of standardised layouts (Teams G,C);
- the use of consistent file types (Teams E,G).

For collaborative work consistency was considered important.

The Principle of Interaction & Reflection

Students applied this Principle, by discussing the stored information through the use of -

- discussion boards, discussion threads, email or blogs. (Teams A,B,C,D,E,I)

Working asynchronously, students found it hard to interact and reflect on information without the ability to discuss it with the other side of their teams.

Some students found time impacted on the use of this Principle suggesting that on a short project *"….. that you can remember things – your own memory comes into play"* (PFG5) and therefore there is less need to reflect back on stored information. However not all students agreed with this and felt the need to record information so as not to forget.

The Principle of Context and Clarity

Students realised that in distributed design work greater context was needed; more informal information to explain the formal documents they typically stored. Methods used by the teams to add this context included –

- including informal information in most communications (all teams);
- profiles of team members and adding of personal information (Teams B, G);
- a Q&A session in a discussion thread (Team A);
- use of video to explain concepts further (Team C).

Two of the Swinburne sides (Teams B, E) noted they *'never'* took the *Principle of Context and Clarity* into consideration. Team B didn't understand the meaning of the Principle and whilst examination of Team E's site showed some informal information Team E did not return emails for further explanation.

At the Focus Group students reported context and informal activity strengthened relationships which the students then related to better outputs. Several teams exchanged profiles and personal information however this was found to be insufficient; with everyone having 'generic' profiles on social networks such as *Facebook*, etc. More informal engagement and information was required. Some teams equated a lack of provision of context to stored information to be a lack of engagement on the part of team members.

The Principle of Information Type

In considering this Principle students noted they stored a wide range of information carriers - images, pictures, sketches, video, text, CAD work, mind maps, concepts and links, (Teams C,D,E,G,I) File formats included – excel and Word docs, pdfs, PPTs, jpgs and pngs.

The Strathclyde side of Team D was the only side to report they *'never'* considered this Principle, due to the small quantities of information they were working with. The Strathclyde side of Team E reported that their tool (*Wetpaint*) limited the type of files that could be uploaded and the Strathclyde side of Team G noted *Google Docs* also had limitations on some file types, for example *Solidworks*. These are issues that might affect the choice of technologies to use as well as the files types to store.

One participant at the Focus Groups suggested that this Principle might be a little too broad however not everyone agreed –

> *"Is that not quite a good thing though to allow you to have that broadness to allow that free design?....."* (PFG3)

The author agrees with the latter since one of the reasons Principles were selected as a tool and method for change in distributed-design information storing behaviour was their broadness and flexibility of use.

The Principle of Quantity & Size

Two Strathclyde sides (Teams C,D) noted they *'never'* considered the amount of information (how much) they stored since they had ample storage space and never reached the storage capacities. Team D did not consider this principle to be important on a short project. They also reported uploading difficulties to *Google Docs* due to file size limitations. If the team had considered this Principle then they may have chosen to use another technology or to limit the size of files, for example shorter video clips, lower resolution images, etc. to avoid the issues they experienced. Other teams noted that they considered or applied the Principles *'early on'* or *'all throughout'* but little evidence was actually given of application. With increasing storage space available at decreasing costs there is concern that teams are not evaluating the quality of distributed information on project work and simply storing information because they can. Students need to be capable of evaluating information worth in different contexts. There is recognition however amongst students that some consideration should be given to the amount of information stored. Team A noted that consideration of this Principle should make teams aware there was a balance between limiting what you store and storing too much, leading to 'information chaos'. Team I was in agreement. This Principle should be considered so as to avoid overloading the online shared workspace with too much worthless information.

The Principle of Memory

This Principle was designed to encourage the storing of a comprehensive picture of project processes and outputs. The Swinburne side of Team D reported that *Google Docs* was a -

> *"good method of providing a good history of design files but offered up little memory of the communication history".* (Team D, SWq)

To ensure a more comprehensive memory the team linked *Google Groups* to *Google Docs* to capture and retain a record of the more informal communications which the team found valuable.

The greatest numbers of sides of teams reported they *'never'* considered this principle. (Strathclyde side of Team A and Swinburne side of Teams E,G) Strathclyde students accredited this to a lack of time. They didn't revisit the information or reflect back on it. Students noted that due to short project length, that fewer of the project problems, processes and rationale were recorded. In the case of big projects they felt it would prove valuable.

At the Focus Group the Team A participant recognised the value of stored information as a *'memory'* for reuse and future learning.

> *"…..I think it's very important to have the Principle of Memory if you want to optimise a process, I mean like it's....if they were to do another project along the similar lines again..…probably go back and see …..how we can do things better and so unless you have stuff documented you can't really revisit and try to do things differently."* (PFG2)

He also brought the discussion around to the key reason for having an effective PM in industry –

> *"….. another aspect of this in the industry, I mean, you never know when a person who is working on a project…..for some reason he chooses to quit the company..….then you have nowhere to go and actually dig out for information. So you need something like this then to actually retrace the steps and retrieve information."* (PFG2)

One thing which struck the author when questioning students at the Focus Group was the difficulty in assessing the true use of the Principles in the project. Students seemed to suggest that they were using the Principles more implicitly rather than explicitly. In other words they were aware of them throughout the project but were not constantly referring to them during the project. They reported they would welcome greater intervention of the Principles by teaching staff.

7.5.3 How the Principles helped teams

At the Focus Group the students returned 51 responses on the how the Principles helped their teams. See Table 7.3. The responses were categorised and coded; see Appendix 7.7. The frequency of each category was noted to give some indication of how the Principles supported the students most. Many were reported to help with issues previously identified in the Case Studies which supports the internal validity of the work.

Consideration of Principles helped teams to –	**Category Coding**	**Category Mentions**
Access information easily	A	7
Structure and organise distributed information	OS	7
Adopt a Strategic approach to distributed information management	St	5
Keep information Clear and Concise	CC	5
Document throughout all stages, be consistent	DT	4
Realise need to be Familiar with Tools	FT	3
Strengthen Teamwork and Collaboration	Tm	3
Think about Usefulness and Value of information	UV	3
Realise the Importance of Informal Information to add Context	C	3
Work towards a Project Outcome	PO	3
Increase Understanding of what they were expected to do	U	3
Remember Information (Memory)	M	2
Reflect on information	R	1
Learn from problems, Lessons Learnt	LL	1
Be aware of Security	S	1
Total		51

Table 7.3: Activities supported by Consideration of the Principles

The Principles were most beneficial in -

- accessing information easily;
- structuring and organising distributed information. This corroborates with the highest *'effectiveness'* ratings returned for the Principles from the Questionnaire (for Strathclyde sides, see below).
- playing a central role in the development of an information strategy; and
- the making of information clear and concise was noted by several teams too.

Other ways in which the Principles helped students were:

- to support documentation throughout the project;
- the realisation that they needed to be familiar with the technologies before starting the project;
- to strengthen team work;
- to think about the value of information; and
- about how informal information could add context; and,
- to work towards project outcomes.

These were all problematic areas in the first studies to greater or lesser extents. The Principles were less instrumental in getting the teams to reflect on the information they had stored with only two mentions of *'reflection'* and *'lessons learnt'*.

Several of the Principles, whilst meant to exist independently did have strong interconnectivity with each other. One of the underpinning pedagogies of the Principles was that their effectiveness should be greater when more principles are operational (Nicol, 2007). The more principles applied, the greater the opportunity for the principles to mutually support each other. Students at the Focus Group recognised this interconnectivity between some of the Principles. Team G found that –

> *"….we have for example … a folder with meetings and conversations and all those things ….. and people would know they were supposed to put our meetings and our conversations in that folder. And they would do it, so the Principle of Structure would also help with the Principle of Location and Consistency."* (PFG5)

Team A suggested that strategy impacted on tools to be used in a project –

> *"… the tools which we used also depends upon the kind of strategy the team decides to implement or allow, early on in the project…. So, it's very strategy dependent, you know."* (PFG2)

7.5.4 Impact of Principles on Teams

Key to the questionnaire was a series of sixteen survey-style questions seeking agreement or disagreement with closed statements generated from the aims of the Principles, the Principles themselves and the use of the Principles. For complete record of responses see Figure 7.3. See Appendix 7.8 for Strathclyde and Swinburne responses.

The closed statements indicated that teams were very much in agreement with –

- the structuring and organising of project resources (100%);
- knowing where project information was (100%);
- the creation of a strategy or rules (93% in agreement, with the Swinburne side of Team B disagreeing but this could not be followed up);
- the interaction and reflection on stored project information to support decision making and to progress work (93% in agreement, with 1 Swinburne side neither agreeing nor disagreeing). This result was higher than anticipated as several students at the Focus groups noted they did not reflect on stored information. In theory students know they should be reflecting but this is still less well demonstrated in practice. Students have noted this is often due to lack of time.
- And, the storing of information should be frequent throughout distributed projects (93% in agreement, with the Swinburne side of Team E neither agreeing nor disagreeing).

86% of responses noted that overall the Principles helped support information storing on the 2009-2010 Global Design project (with 14% neither agreeing nor disagreeing); and that 71% felt they contributed to a satisfying distributed team experience (with 29% neither agreeing nor disagreeing). This is a positive outcome. In the previous cases studies all teams expressed some level of frustration at points during project work. Surprisingly, whilst the Principles helped support their distributed-design information storing practices, only 57% of the responses considered their information management skills to be improved (36% neither agreed nor disagreed and 1 Swinburne side disagreed (which could not be followed up).

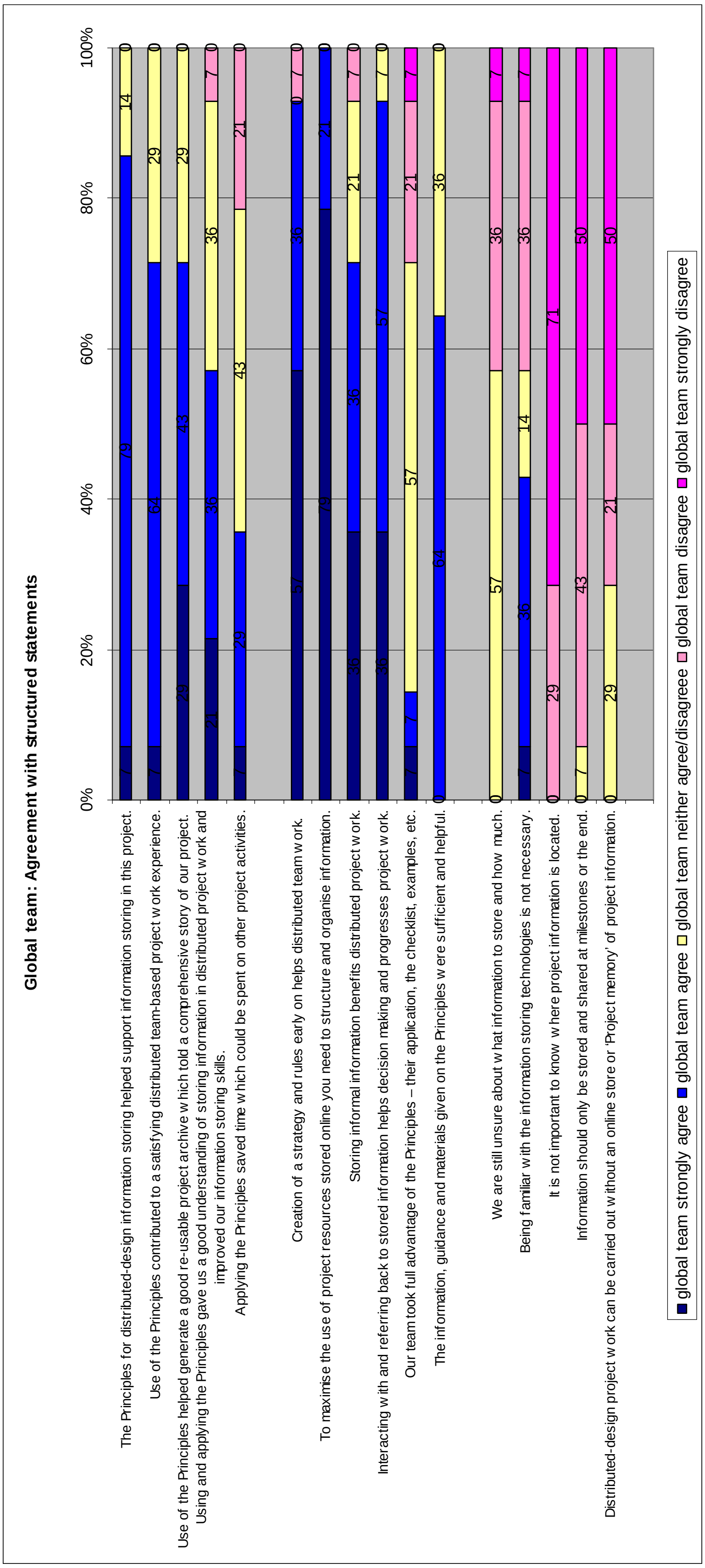


Figure 7.3: Results of the Validation Structured Statements for Global Team

Overall 71% of responses agreed (29% neither agreed nor disagreed) that the Principles helped to create a reusable project archive and that distributed project work required a *Project Memory*.

> *"A project needs a strong Project Memory. This memory enables the designer to review the design and evaluate if the progression of the project is in the right direction. Sorry about the late reply. I do not use this email regularly."* (Team D, SWq)

More Strathclyde sides of teams agreed (86% agreed: 14% neither agreed nor disagreed) than Swinburne sides (57% agreed: 43% neither agreed nor disagreed). The Strathclyde teams required a record of project processes and outputs to refer back to for reflective report writing purposes later on in the class which suggests that having an educational need or purpose, such as reflection, for a *Project Memory* engages teams more with the Principles.

71% of responses agreed that informal information benefitted distributed project work (with 22% neither agreeing nor disagreeing and only one Swinburne side disagreeing). This is encouraging, that although students previously found storing informal information difficult and time consuming, the need to do so to add context was recognised in almost three quarters of responses.

There were three lower than expected results –

1. The number of students agreeing with tool and technology familiarity before project work, was low – 42% in agreement, 14% neither agreeing nor disagreeing and 42% in disagreement. The negative wording of the question could have affected responses. Three of the Swinburne-sides felt it wasn't necessary to be familiar with the tools pre-project and attempts at confirmation were unsuccessful. Since technologies are central to distributed information storing processes, a lack of ability to use the technologies can impact strategy.
2. Secondly, only 43% of responses noted students were now more confident about what information and how much to store (57% neither agreeing nor disagreeing). This correlates to one of the lowest 'effective' values (3.6: combined) for the *Principle of Information Type*. See Section 7.5.5 below.
3. Only 34% of the sides noted they took full advantage of the Principles (37% neither agreeing nor disagreeing). The 'self-managed' approach to the use of the

Principles was a contributing factor. Greater emphasis on use of the Principles and intervention of more d-DIS project activities can improve this measure.

Teams welcomed greater intervention through project activities and greater staff emphasis.

> *"We did take some advantage but not 'full' advantage. It is time consuming and we weren't made to do it. Applied some principles but didn't look at checklist during project. Good idea to do but would need staff intervention."* (Team I, Strathclyde,q)

Students did not find the use of the Principles saved time due to the shortness of the project. Only 36% agreed (43% neither agreed nor disagreed and 21% disagreed).

> *"The short term project affected our response. On a long term project – the principles would have had more impact* [in terms of saving time]*."*
> (Team A, Strathclyde,q)

Use of the Principles would be more effective on longer projects for two reasons –

- more time would be available to implement them or carry out project activities related to them; and
- the need for a PM would be greater due to a tendency to forget increasingly greater amounts of project information over longer periods of time.

7.5.5 Effectiveness

Effectiveness of Principles

Local sides of teams responding to the questionnaire were asked to give an 'effectiveness' rating on a scale of 1-5 for each Principle. Effectiveness ratings fell within the range of 3.3 - 4.3; see Table 7.4. This is a good result based on the minimum intervention applied. Strathclyde-sides tended to score slightly more favourably than the Swinburne sides, but not on all Principles. The author recognises this may have been slightly affected by researcher familiarity. Overall, Strathclyde and Swinburne results closely matched. The author had little contact with Swinburne participants other than to distribute and to follow up on email questionnaires.

Effectiveness rating **1 = least effective to 5 = most effective**	**Strathclyde ratings**	**Swinburne ratings**	**Combined (global) ratings**
Overall Principle of Strategy	3.9	4.0	3.9
Principle of System Support	4.0	3.7	3.9
Principle of Structure	4.3	3.7	4.0
Principle of Location/Retrieval	4.3	3.7	4.0
Principle of Consistency	3.9	4.3	4.1
Principle of Interaction and Reflection	3.9	4.0	3.9
Principle of Context and Clarity	4.0	3.3	3.6
Principle of Information Type	3.4	3.7	3.6
Principle of Quantity	4.0	3.9	3.9
Principle of Memory	4.1	3.3	3.6

Table 7.4: Students' reporting on the Effectiveness of each Principle

Combined results indicate global teams found the *Principles of Consistency*, *Location/Retrieval* and *Structure* to be the most effective Principles; closely followed by the *Principles of System Support*, *Interaction & Reflection* and *Quantity & Size*.

The lesser effective results need further discussion. The combined 'effectiveness' rating for the *Principle of Context and Clarity* (3.6: combined) and for the *Principle of Memory* (3.6:combined) were affected by a non-return of an 'effectiveness rating' from Swinburne Team B. These students did not understand the first Principle and gave no comment on the *Principle of Memory*. This suggests that there is still an element of misunderstanding. The *Principle of Context and Clarity* was also given a low 'effectiveness rating' by the Strathclyde-side of Team D; noting that their tool (*Google Docs*) was not adequately set up to store informal information and they had to use *Google Groups* alongside to communicate, for best effect.

The students found the *Principle of Information Type*, to be the least effective. Of all the combined ratings, it scored the fewest '*most effective*' ratings and was amongst a few principles having the most '*1*' or '*2*' ratings (*1=least effective and 5=most effective)*. With the requirement for principles to be both broad and flexible to suit many applications and situations there will always then be varying views on their effectiveness dependent on different contexts of use.

Students found that some of the Principles worked most effectively together and indeed depended on each other. For example, students at the Focus Group suggested that the *Principle of Context and Clarity* needed to be applied for the *Principle of*

Interaction & Reflection to be effective. The context at the time has to be captured to make reflection on stored information meaningful and worthwhile.

Finally, when students were asked if they were in a better position to know how to store project information in a distributed context, having been introduced to the Principles, they were in strong agreement. They noted though they would be more beneficial, the longer the distributed project and that the Principles needed to be enforced to a greater degree through project activities.

Effectiveness of the Principles Material

The effectiveness of the Principles themselves is evidenced in the preceding section. Students found the *Principles Framework* particularly useful in its diagrammatic form. They reported it was a good visual to follow with the majority of students referring to it mainly at the beginning of project work. Even with the minimal intervention of the Principles, a greater awareness of distributed information storing has been achieved for participating students. However, despite almost two thirds of students agreeing the supplied material on the use of the Principles was helpful, on reflection, the author feels the methods used to implement the Principles were less than effective. The use of the Principles should have been more instructional, even at 5th year and Postgraduate levels. Whilst the Principles were understood by the majority, following their introduction, having a presentation, a list of Principles, the guidance document and reflection at the end was not sufficient. For even greater impact teams should have been made to reflect on their information storing practices during distributed project work and to engage in project information storing activities. For example, the requirement for a document outlining an information strategy; or the examination of information and knowledge structures mid way for the purpose of improving storing. Participants at the Focus Groups found the Principles to be most beneficial at the beginning of project work and the Principles Framework to be a valuable guiding ‘visual’. Discussion of past examples of information storing behaviour (especially when problems occurred) proved most enlightening and at the same time produced a lot of laughter with moments of recognition and realisation.

7.5.6 Future Use of Principles

At the Focus Group participants all agreed they would use the Principles in future distributed-design project work, giving their reasons, see Table 7.5 -

Use Principles in future to –	Code	Number of respondents mentioning item
Adopt a Strategic approach to distributed information management	St	3
Document throughout all stages, not lose information	DT	2
Impact on time	T	2
Organise and Structure distributed information	OS	1
Realise need to be Familiar with Tools	FT	1
Strengthen Teamwork and Collaboration	Tm	1
Remember Information (Memory)	M	1
Total		11

Table 7.5: Content Analysis of Responses to Question 2 of Focus Group

They expected the Principles would be most beneficial in supporting the development of a strategic approach to distributed information management and to retain valuable information. On longer projects they anticipated their implementation would also save time.

Part 2: Examination of a Project Memory

Finally, this work would not be complete without the examination and evaluation of one of the *Project Memories* from the 2009-2010 Global Design Project, generated as a result of considering and using the set of guiding Principles for d-DIS. By applying and using the Principles for d-DIS students should achieve a more effective PM and increase their information storing practices. This section of the thesis presents the findings. It then concludes by bringing together the work by presenting a *Project Memory Model* based on the literature and the findings from the earlier case studies. As a reminder, this work defines a *Project Memory* as –

> *"a store of the explicitly represented formal and informal information and knowledge acquired and generated during distributed design team-based project work to support decision making and shared understanding. It should be dynamic and active; interacted with and reflected upon during distributed team-based project work, in addition to acting as a useful project archive for learning opportunities thereafter. It*

> *stores both process-related and product output-related resources; the context, rationale, lessons learnt as well as the results."*

Greater use of the Principles will lead to achieving satisfaction with the criteria for a PM.

7.6 Project Memory Information Content Analysis – Case Study 7

This Section reports on the examination of the information stored by one team, in order to determine what effect the use of the Principles had on a *Project Memory*. This work forms Study 4, Case Study 7. In the context of the 2009-2010 Global Design Project, students from Strathclyde University, UK and Swinburne University, Australia asynchronously designed a coffee cup holder. (See Appendix 4.1 Case context details) The project activities were the same as in previous years, with a few changes to accommodate the introduction of the Principles. (See *Educator's Principles* in Appendix 7.1 for changes made to Global Design Project.) The same research methods as in the previous case studies were used (see Chapter 3) – Case Studies, Content Analysis of Data/Documents, Questionnaires, a Focus Group and a Semi-structured Interview.

Sampling

Of the six teams represented at the Principles Focus Group, Teams B and I were approached to take part in the further study of the *Project Memory* information content, on the basis that their UK sides had consistently considered the Principles *'all throughout'* the project. Further to this, Team B UK was available to commit additional time and was therefore selected. Data and document analysis was carried out on Team B's stored information content in the same manner as the previous Case Studies, pursuing the same research questions – *where is information stored; what information is stored; when is the information stored and how*? This was followed by a semi-structured interview with the UK side of the team to confirm and expand on the findings.

The next sections will now present the findings of Team B's stored project information in relation to the five criteria for a Project Memory, along with further discussion.

7.6.1 Centralised Store – 'Where' information was stored

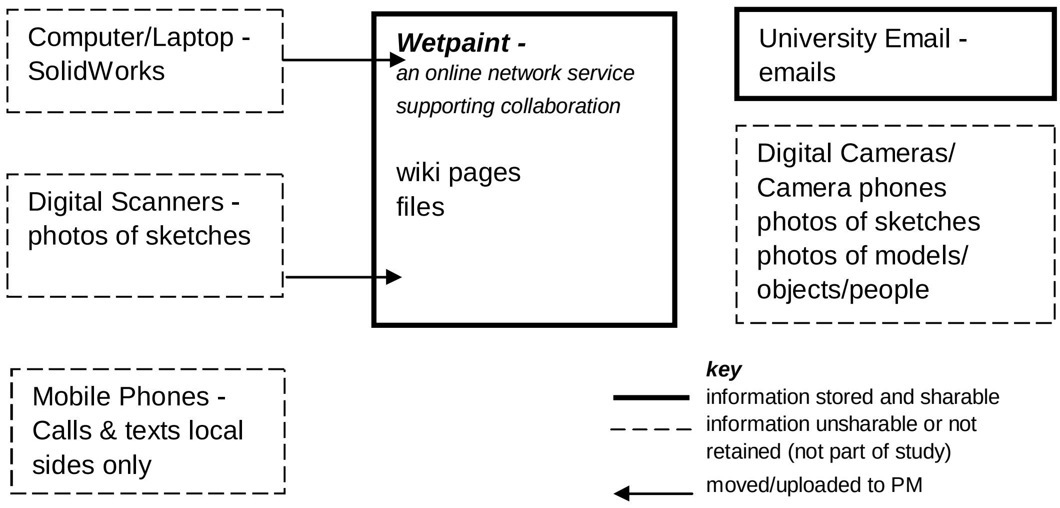


Figure 7.4: 'Where' Team B stored project information

Team B took into account the *Principle of System Support* and ensured that all project information was shared and stored on a website for shared access and group working – *Wetpaint*. Figure 7.4 shows all technologies used by Team B. Further detail can be found in Appendix 4.2.

Feedback from Team B regarding *where* information was stored revealed -

- Work was kept centralised and most communications took place in *Wetpaint*, in posts and on a Discussion Webpage. Some emails were not uploaded to *Wetpaint* – these remained on student's university email accounts. At interview Team B noted that the Swinburne students had used university email accounts to send *Solidworks* files to UK side due to *Wetpaint* file size limitations. Students noted that whilst they tried to keep all information in the same centralised place it was difficult not to use easier (but less appropriate) technologies, for example email which can easily result in the loss of information amongst distributed team members. (w;v) (See Appendix 3.5 for coding)
- The UK students familiarised themselves with all the basic features of *Wetpaint* before starting the project and as such found the system *"…easy and simple to use."* (B.2,v)

- End of year workload meant that the Swinburne students had very little time pre-project to familiarise themselves with the tool and had a few issues locating information on first use. (B.1,v)
- Keeping information centralised certainly helped information access and retrieval. (B.2,v)

It was evident that through the use of the Principles the team had tried to keep all project information in a centralised place for ease of access. As a result the experiences of difficulties in finding information or losing information were not mentioned during the semi-structured validation interview.

7.6.2 Contains both Formal and Informal Information – 'What'

Another of the criteria for a *Project Memory* is the inclusion of informal project information in addition to the formal project information traditionally stored and archived. Informal information adds context required for work in a distributed situation and supports team cohesion. This practice-related information is valuable in terms of reflection and in its re-use, for further learning opportunities.

The project information in Team B's Wetpaint site and emails was examined. See Appendix 4.3, Case 7, for data.

In the Wetpaint Wikis

Almost equal amounts of instances of information were stored - **Formal (53%)** and **Informal (47%)**, see Figure 7.5 (Appendix 4.3 for instances). For the top five information content types stored see Appendix 4.4, Case 7, content in wikis.

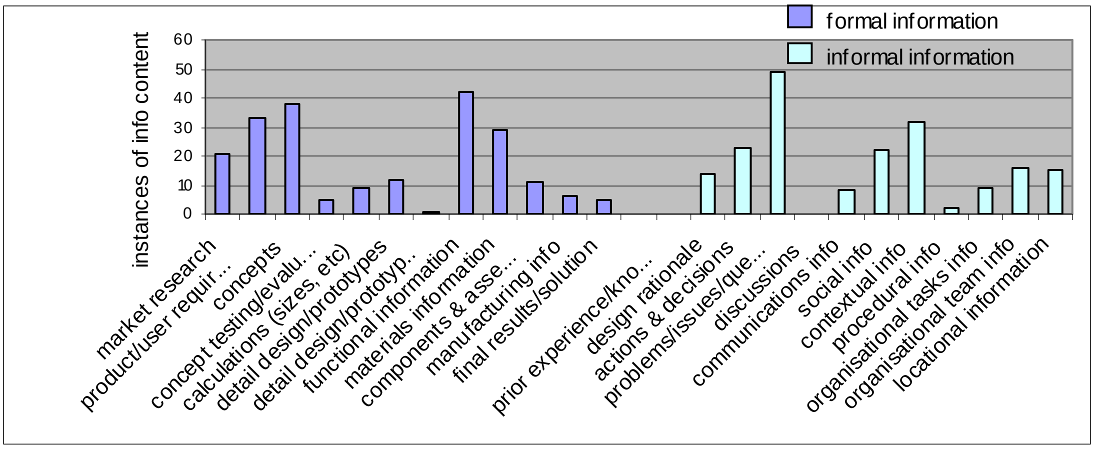


Figure 7.5: Instances of Information Content stored in Team B's Wetpaint Site

In Emails

Instances of **Informal information** content were **100%**, see Figure 7.6, (Appendix 4.3 for instances). For the top five information content types stored, see Appendix 4.4, Case 7, content in emails.

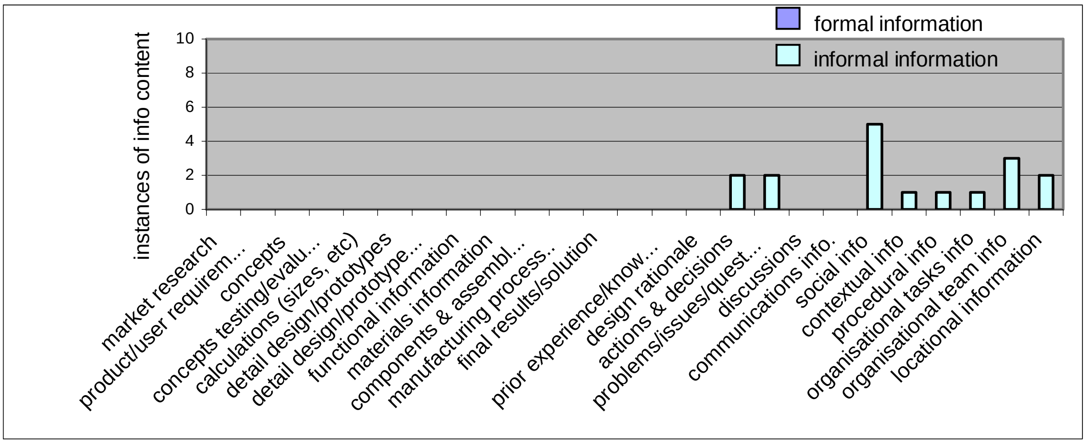


Figure 7.6: Instances of Information Content in Team B Emails

Amount of Information

Overall, the information content across the Wetpaint wikis and emails evidenced almost equal amounts of **Formal (50.5%)** and **Informal information (49.5%)**, see Figure 7.7. Overall, the Strathclyde students stored more instances of information content in *Wetpaint* (74%) and in emails (65%).

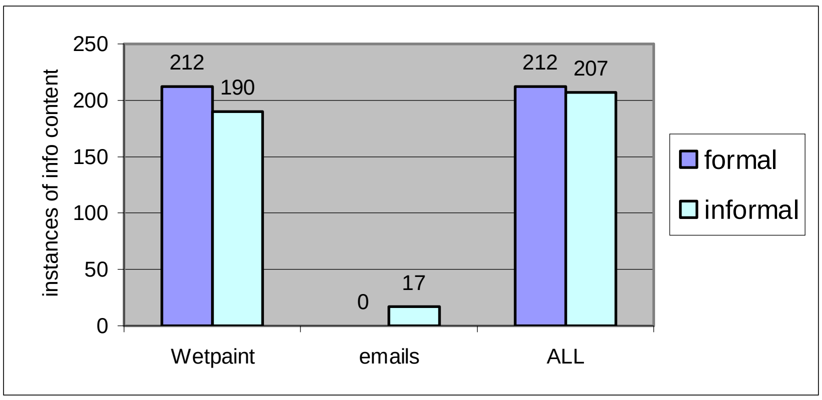


Figure 7.7: Team B Formal and Informal information across *Wetpaint* and emails

Feedback from Team B regarding *what* information was stored revealed –

- Like previous students, when asked at interview the Team B UK students were surprised at the (high) amount of Informal information they had stored. They noted that both sides of the teams had stored a lot of information about themselves, *social information.* (B.1, B.2,v) They agreed that storing informal information added shared meaning and understanding.
- They also noted the Principles had made them aware of the need for making things clearer due to the distributed nature of the project. (B.1, B.2,v)
- Communications were kept very short (a few lines in most cases). (B.1,v)

Whilst a higher percentage of informal information was anticipated following the use of the Principles, this result (53% Formal information content and 47% Informal information content on the *Wetpaint* site; and overall 50.5% Formal and 49.5% Informal) is still very satisfactory as it matches recommendations made from the previous Case Studies. A few aspects of Team B's storing and use of the Principles contributed to slightly less Informal information content being stored. These included the fact that Team B's communications were kept very short (a few lines in most cases). The earlier case studies showed that, typically *communications information* is informal in nature. More Informal information would have resulted from longer communications. Additionally, the Swinburne students didn't consider or apply the *Principle of Context and Clarity,* storing only 8 instances of *contextual information.*

It was promising to see that students were storing information relating to project practices and processes, for example, *problems/issues/questions, contextual information, actions* & *decisions,* making the PM useful for decision making and reflection during the project, and for other for educational activities later.

7.6.3 Comprehensive record – 'What'

Information Carriers (Wetpaint)

Information was **richest as text (62%)** on the wiki pages. Photographs or scanned sketches (11%) and photographs of physical models/objects/people (8%) were also used. For the different information content stored in *Wetpaint* see Figure 7.8. For more data on information carriers see Appendix 4.6.

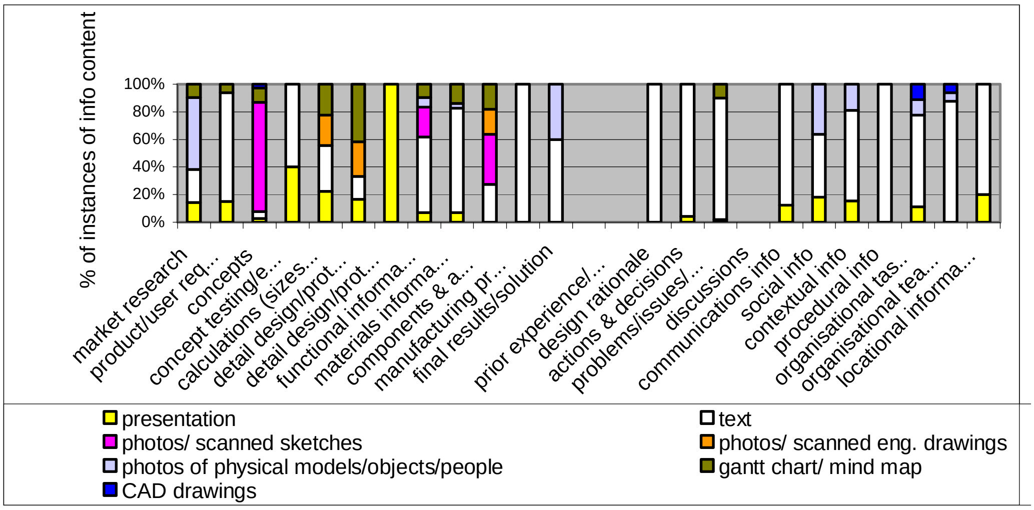


Figure 7.8: Percentage of Information Carriers for each Information Content type

Feedback from Team B regarding *information carriers* stored revealed -

- At the interview students noted that not everything had been stored but *"Pretty much, about 80%"*. (B.1,v) For example, some SolidWorks files were lost when Swinburne students emailed this information rather than using *Wetpaint.* (This was a system limitation.)
- A few early ideas were not included in the PM and remained on paper, unshared and unstored.
- A key driver for the UK students when considering the Principles and the content of the PM was the need for adequate information to write up the reflective report following the project. In putting together her report one student noted – *"…every information that I wanted to refer to, it was on Wetpaint."* (B.1,v)

Team B felt they had achieved a fairly comprehensive record of their project outputs and practices by keeping information concise and meaningful, by applying the *Principle of Context and Clarity*. Having a need for the PM , in the case of the UK students being required to write a reflective report, gave students an incentive to store information and helped students to understand the requirement for a comprehensive PM in industry.

Text was still the preferred information carrier, particularly in asynchronous distributed work. Again, similar to the other case studies, *photographs or scanned sketches* and *photographs of physical models/objects/people* proved valuable to students as pictures conveyed a lot of information. However, these needed to be supported by text in order to be of most value in providing a comprehensive record.

7.6.4 Contributed to frequently – 'When'

The *Principle of Consistency* relates to how often information is stored during distributed project work and recommends for best effect that information is stored frequently by both sides of a global team. UK students noted they considered this Principle *'all throughout'* the project and Swinburne students considered this *'early on'*. Figure 7.9 shows that information was stored frequently in the first week by all team members; sharing information about market research, concepts and evaluation of these concepts. This is a positive result. However when tasks became more collocated in Weeks 2 (detailed design, Swinburne) and in Week 3 (prototyping, UK) there was a tendency not to share so much local work with global sides.

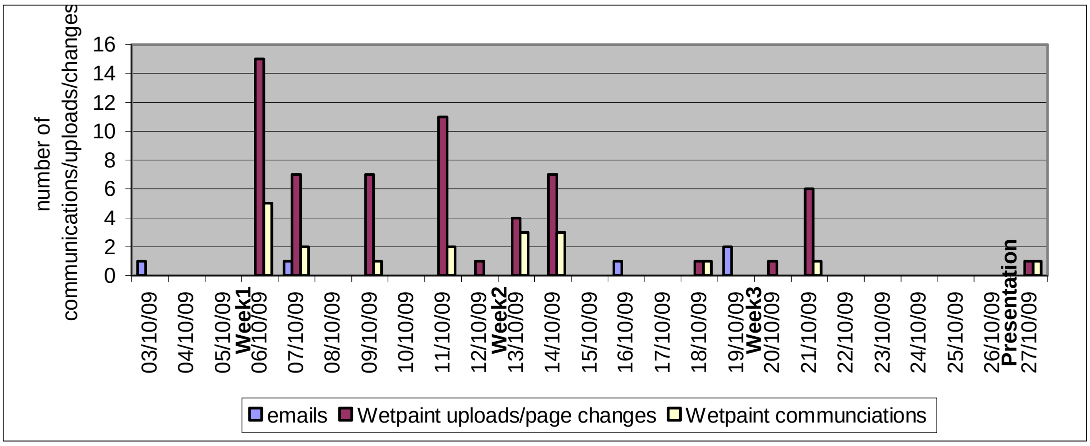


Figure 7.9: 'When' Team B contributed to their *Project Memory*

It was felt by the author that Team B did not apply the *Principle of Consistency* as well as they could have. Information could have been exchanged more often, especially during local-side activities to keep all members of the team aware of project development and progress. Distributed project work should encourage and involve more global activities and less local-side activities to ensure more frequent storing of distributed-design information and keep team cohesion high. UK students agreed that receiving information frequently was motivating –

> *"It was quite nice at the beginning when you uploaded something and the next day something else was done."* (B.1,v)

7.6.5 Organised and Structured – 'How'

The final criterion for a *Project Memory* is organisation and structure. All organisations should have good project management principles and appropriate systems installed before working on distributed projects. (Hertel et al., 2005) On examination, Team B's final PM was found to be well structured and information easy to find. To an extent *Wetpaint* had pre-designated areas where information could be stored and shared, for example a photo gallery, discussion area; and the facility to build web pages, accessible via a simple menu bar on the main homepage.

Feedback from Team B regarding *how* information was stored revealed –

- The UK students developed their team's project information strategy, creating separate web pages ready to receive project information for each stage of Team B's design for the coffee cup holder, and each team member. Pages were one click from the homepage and easily accessible. Students recognised that whilst this worked well for the timescale of their project, on longer projects they would have created more levels and sublevels. (B.2,v)
- The UK side of the team explained they had determined the strategy for storing project information in order to save time and give a structure to the work. (B.1,B.2,v)
- The Swinburne students accepted the UK recommendations for a strategy largely due to their time limitations. The Swinburne side, not having been involved in the strategy formulation early on, coupled with their unfamiliarity with *Wetpaint*, reported problems finding information on the site initially. However this was short lived. (Sw,q)
- At interview the students agreed that, to make best use of shared distributed information, it had to be organised. One UK student noted –

> *"If it's not clear, or organised, it's like chaos so the other members maybe won't understand what you have to say, so while uploading you have to have clear explanations of why and what you are doing."* (B.1,v)

The *Principle of Strategy* recommends that all members of the global team contribute to a distributed design information storing strategy for equal ownership, adoption and contribution. Inequality across global teams can be a result of not sharing project information (Ardichvil et al., 2003) however this was not the case for Team B.

So, even the low impact implementation of the Principles in the 2009-2010 Global Design Project and their subsequent use by Team B, had an impact on their *Project Memory*. Distributed project information was stored in a centralised location – *Wetpaint* (with the exception of 5 emails and 3 files, due to systems constraints). Content Analysis of the stored documents evidenced equal amounts of Formal and Informal information, meeting the recommended baseline. Information was organised and structured making it easy for students to access and retrieve project information; and students confirmed a fairly comprehensive record had been achieved. The need to contribute information frequently was less well achieved. This could be resolved through re-design of project activities.

7.7 Project Memory Model

The concept of the *Project Memory* as presented in this work is central to the Principles Framework and can be represented as a simple model based on the literature, the findings and Recommendations from the case studies, and from the validation of the Principles and Project Memories, see Figure 7.10.

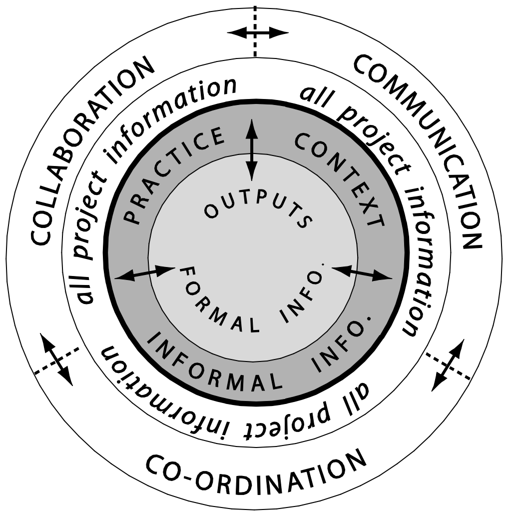


Figure 7.10: Project Memory Model for d-DIS

At the core of the *Project Memory Model* lies the PM itself (shown by dark line) with both formal information, the outputs, traditionally generated as a result of collaborative work; and at least equivalent amounts of informal information, capturing the practices, processes and context underpinning the shared project activities. The linking between this formal and informal information is key to supporting a shared understanding. One such method used by student teams to link the Formal and Informal information was hyperlinking on wiki pages. This added clarity and meaning to theei stored information. The PM information content, formal and informal, is a subset of all generated project work and the sum of all information shared by the global team, identified by the team as of value to decision making and product development; represented by the second outer-most ring of the model.

Finally, with reference to the Co-operative Triangle for effective distributed design introduced earlier in the thesis (MacGregor, 2002; adapted from Teufel et al., 1995), a PM can be seen to be central to and supports the activities of distributed communication, collaboration and co-ordination. See Figure 7.11.

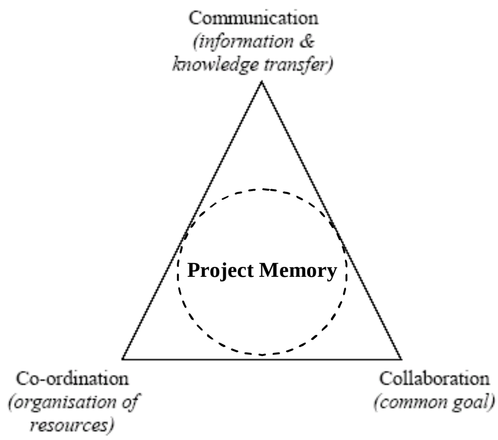


Figure 7.11: A Project Memory and the Co-operation Triangle. Based on MacGregor (2002, p.19)

7.8 Summaries

Principles

Chapter 7 presented the Validation of the Principles in the 2009-2010 Global Design Project Work, with students from Strathclyde, Glasgow and Swinburne, Australia. The Chapter began by outlining use of the Principles by educators. The revision of earlier Global Design Projects, by the author, was used as an illustrating example. The Implementation of the Principles in the 2009-2010 Global Design Project was then described, detailing the presentation of the Principles to the students and the supporting material supplied to each team – (i) the *Principles* and *Framework* and (ii) the *Principles for d-DIS Guidance Document*. Teams were advised to use this documentation throughout distributed project work. Questionnaires (including some survey-style statements) to both Strathclyde and Swinburne students and UK Focus Groups were used to validate the Principles. Consideration of each of the Principles, by the student teams, was then outlined in detail. Students gave effectiveness ratings to each of the Principles. The *Principles of Consistency, Structure, Location/ Retrieval, Strategy, System Support* and *Quantity* proved to be the most effective across the global teams. Overall there was satisfaction with the Principles but both students and the author felt that their implementation and intervention could have been more influential for an even greater impact. The intention was to change student distributed-design information storing practices and the Principles were shown to facilitate this.

Project Memories

A Project Memory is a dynamic and active store of both explicitly represented formal and informal information and knowledge acquired and generated during distributed design team-based project work to support decision making and shared understanding. It is the mechanism by which distributed teams share information and an understanding of the project problem. The second part of this Chapter showed that use of the Principles for distributed-design information storing helped students to create a better Project Memory. A PM has been shown to support student learning: playing a role in supporting knowledge building and knowledge sharing within teams (Roschelle & Teasley, 1995; Dillenbourg, 1999) and enabling students to collaborate in the building of a shared representation of the design problem (Nicol et al, 2005). It provides a rich repository from which, lessons can be learnt; reusable learning objects can be harvested; and opportunities for reflection can be afforded.

The content of one distributed team's Project Memory from the 2009-2010 Global Design Project was analysed against the five key criteria for a PM (outlined in Chapter 2) using the same research methods for data collection and analysis as described in Chapter 3. The results of the analysis were presented to the UK students of distributed Team B for verification. Using the Principles, students were found to have a well structured and organised online Project Memory and to have stored valuable Informal information relating to project practices and processes e.g. *actions and decisions, contextual information* and *problems/issues/questions.* They reported that keeping information centralised helped information retrieval and that the need for a PM (the writing of a reflective report for assessment purposes) was important.

The Chapter then concluded by presenting a simple visual Project Memory Model tying Project Memories to the three key concepts for cooperation in distributed design – communication, coordination and collaboration.

Impact of Intervention of Principles

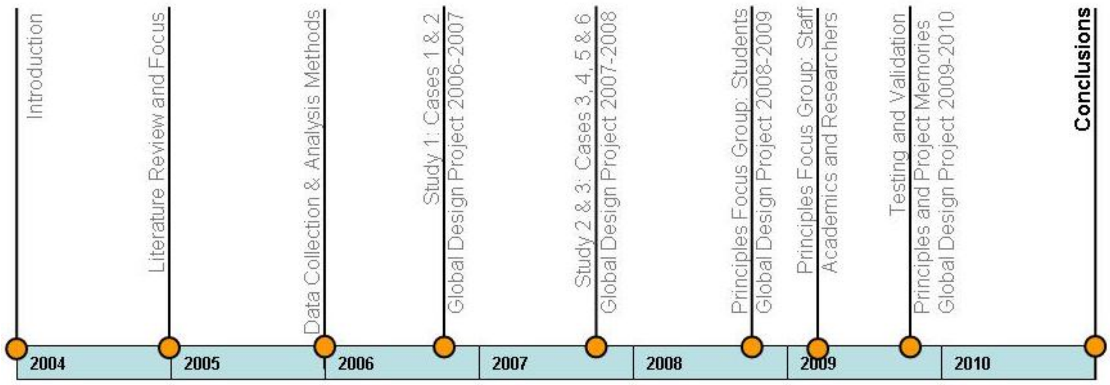
Students found the intervention of the Principles helped in a number of ways – with the easy access of information; the structuring and organising of information; the creating of an information strategy; the making of information clear and concise; the supporting of documentation during project work; the strengthening of team work; and they helped students to work towards project outcomes. The intervention of the Principles can impact on –

- the development of a distributed information strategy;
- improved student distributed information management skills;
- more meaningful and comprehensive stored information;
- a better structured and organised Project Memory; and
- greater satisfaction with the global experience.

It can also possibly impact on other aspects of project performance such as reduced communication delays; equal engagement by all distributed team members; and increased shared understanding of the project problem.

A Project Memory was found to benefit distributed information storing by: co-ordinating project resources; reducing the time spent looking for information; helping to avoid the duplication of information; and making information accessible 24/7. It supported distributed team work by: providing awareness of work at global sides; supporting decision making; supporting collaboration; and providing access to information during project work that told a ‘story’ of design development.

8 Conclusions and Reflection



8.1 Introduction

The final Chapter of the thesis now summarises the research, discusses its value and limitations and suggests potential further work. Section 8.2 will briefly summarise each of the main chapters. The contribution this work makes to knowledge in the field of engineering design education and will be outlined in Section 8.3. The work would not be complete without a personal reflective account of the research and this is contained in Section 8.4.

And finally, with all research work there are numerous constraints which determine the scope of the work achievable in any given time. Therefore Section 8.5 will examine potential future work that can build upon the work contained in this thesis.

8.2 Summary of Work

This Section briefly summaries the work of each Chapter.

Chapter 1 introduced the thesis by setting out the Vision for the work; the Research Aims and the Research Objectives required to achieve these aims. An overall Research Framework was presented for clarity. In order to ensure research rigour a recognised Design Research Methodology was adopted to guide and support the work – *Blessing's Descriptive/Prescriptive Model*. This methodology involved an exploration of the problem area, in this case the poor storing and sharing of distributed-design information by students, before the design of an approach to improve issues. This was followed by testing and validation. Chapter 1 then concluded with the Contribution this work makes to knowledge and a Thesis Map.

Chapter 2 - reviewed the literature in the five key areas relating to the thesis work: Distributed Design, Engineering Information, Information Management, 'Memories' and Design Education; identifying a number of issues associated directly with distributed design information storing. The literature established that still little is known about the use of information and documents by engineers (McMahon et al., 2004) and this work sought to address this, by understanding better how students in a distributed context store design information and knowledge.

Chapter 3 - Chapter 3 presented the various methods used to carry out the research into '*How students store and share design information and knowledge in distributed design team-based project work?'* Review of previous empirical studies in engineering design, both in industry and academia, helped to determine the methods used in the research. These methods included - Case Studies; Content Analysis of data and documents; Questionnaires; Semi-structured Interviews; and Focus Groups. Detailed descriptions of the design and the processes undertaken for each research method were presented. The mixed method approach satisfied the requirement for a depth of understanding and the need for triangulation.

Chapter 4 - presented the many and varied issues the students involved in the Case Studies experienced when storing information in distributed design team-based project work: from information stored in several places; a lack of organisation or structure; and, lost information; to uncertainty as to how much to store; unfamiliarity with tools; and, inconsistency of storing of project information; all contributing to an incomplete and fragmented 'picture' of design development. From the analysis of the stored information content of the distributed student teams and the emerging findings and issues, it was evident that students require guidance and support on distributed-design information storing.

Chapter 5 - Chapter 5 discussed the emerging issues from the Case Studies under a number of categories: *information systems* (where?); *information stored* (what?); *information patterns* (when?) and *information strategy* (how?). From these Issues a series of Recommendations were made to support distributed design information storing. These Recommendations laid the foundations for the set of guiding Principles for distributed-design Information Storing.

Chapters 4 and 5 reinforced early thinking on student information storing practices. The findings and issues outlined in these chapters supported Hypothesis 1 –

> ***Hypothesis 1***
> ***Student information storing practices in distributed design team-based project work are currently inadequate.***

Chapter 6 – made the case for the development of a set of guiding Principles and documented their development from early versions based on the issues in the literature and the emergent issues of the Case Studies, to their refinement through Focus Groups with both Students and Academic Staff. Feedback on the *Principles for d-DIS* and the *Principles Framework* was positive: students and staff considered the Principles would help reduce the frustration and confusion often associated with distributed project work, e.g. lost and incomplete information, lack of context, poor communication, unable to find information, lack of team trust, etc. Students reported use of the Principles would save time; support better collaboration and help them to manage and share project resources better; all allowing more focus on the design challenge. Staff were in favour of the use of the Principles to support students during distributed project work but they also recognised their value in achieving a comprehensive archive which could support project reflection and offer future opportunities for learning. Additionally their implementation would promote good practice in distributed-design information storing and better prepare students for industry and employment in the global market.

Chapter 7 - presented the Validation of the Principles and Project Memories. The Chapter began by outlining how educators could consider the Principles and then described the implementation of the Principles in the 2009-2010 Global Design Project. Questionnaires (including survey-style statements) were used to validate the Principles, along with a UK Focus Group. This section addressed Hypothesis 2 -

Hypothesis 2
A structured set of educational Principles and a Framework will support and improve student information storing practices in distributed design team-based project work.

Students found the implementation of the Principles helped in a number of ways – with the easy access of information; the structuring and organising of information; the creating of an information strategy; the making of information clear and concise; the supporting of documentation during project work; the strengthening of team work; and, they supported work towards project outcomes. Overall, there was satisfaction with the Principles. The intention was to change student distributed design information storing practices and the Principles were shown to facilitate this. This Chapter concluded by outlining the analysis of the content of one distributed team's PM from the 2009-2010 Global Design Project which showed that use of the Principles supported a well structured and organised online PM containing information relating to project practice and process, e.g. *actions & decisions*, *contextual information* and *problems/issues/questions.* Hypothesis 3 was addressed –

Hypothesis 3
Clear recommendations on criteria and content for a Project Memory developed by applying a structured set of educational Principles and a Framework will support and improve student information storing practices in distributed design team-based project work.

A *Project Memory* was shown to be central to distributed design information storing and to the *Principles Framework*. It provided a mechanism by which distributed teams share information and understanding of the project problem. A PM was found to benefit distributed information storing; support distributed team work and support student learning. This Chapter presented a simple visual *Project Memory Model* tying PMs to the three key concepts for Cooperation in distributed design – Communication, Coordination and Collaboration.

8.3 New Contribution to Knowledge

Figure 8.1 relates the objectives set out in the thesis to the new contributions made.

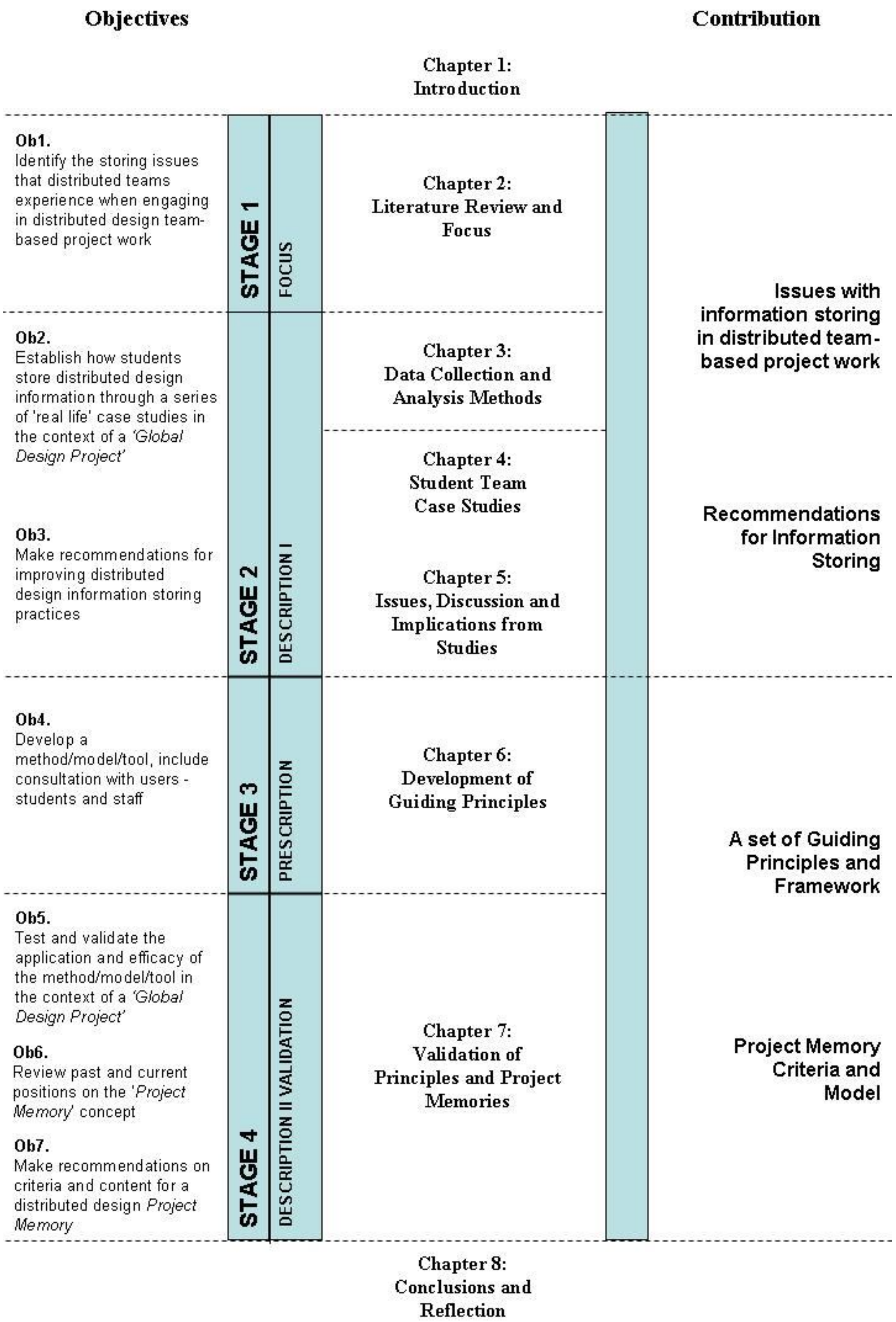


Figure 8.1: Thesis Objectives and Thesis Contributions to New Knowledge

The thesis contributes to new knowledge in four ways –

1. Firstly, this research offers a clearer **understanding of the information that engineering design students store** when carrying out distributed design project work. It does this by presenting the results and findings of six Case Studies into *"where, what, when how and why students store distributed-design information"*; and,

2. It makes a series of **Recommendations** to support the issues student teams experience in distributed-design information storing.

These two contributions satisfy the first three objectives set out at the beginning of the PhD research –

- **Objective 1** - *Identify the storing issues that distributed teams experience when engaging in distributed-design team-based project work.*

  In Chapter 2, a review of the literature identified issues that exist in relation to distributed design, engineering design information management and set this in an educational context.

- **Objective 2** - *Establish how students store distributed design information through a series of 'real life' case studies in the context of a 'Global Design Project'.*

  Greater insight was afforded through the in-depth studies into student information storing behaviours. Chapter 3 outlined the research methods used to undertake the work and Chapter 4 presented the findings and the issues experienced by the six global teams under investigation.

- **Objective 3** - *Make recommendations for improving distributed design information storing practices.*

  Chapter 5 examined the issues students had with distributed design information storing and proposed a series of Recommendations to address these issues. The majority of these Recommendations form guidance within the *Principles for d-DIS Guidance Document.*

Most importantly, this work offers an intervention to improve the practice of those working in distributed environments -

3. It offers a set of **guiding Principles and a Framework for distributed-design information storing** which will support students' storing and sharing of information and knowledge and improve the student experience in distributed team-based engineering design work.

This contribution supports the following two objectives -

- **Objective 4** - *Develop a method/model/tool, include consultation with users* **-** *students and staff.*

  In Chapter 6 the case is made for a set of Principles to support distributed-design information storing. Building on the issues from the literature and the detailed examination of the Case Studies, a set of *Principles* and a *Framework for d-DIS* were designed, and developed through consultation with students and staff, who either had experience of, or were experienced in, distributed team work.

- **Objective 5** - *Test and validate the application and efficacy of the method/model/tool in the context of a 'Global Design Project'.*

  Chapter 7 demonstrates the implementation of the Principles in a student team-based distributed-design project context. In the case of the thesis, the intervention used to validate the Principles was minimal, however even this minimal intervention has been shown to be effective in response to the aims set out for the guiding Principles. Responses to questionnaires, especially those of a survey-style nature, and feedback from participating students help to established the effectiveness of each Principle.

And finally, the work makes its fourth contribution to knowledge, by resurrecting the previous theoretical concept of Project Memories, focussing more on its practical implementation.

4. This research work updates the research area on **Project Memories** and contributes further to this research area through the development of a **Project Memory Model** to support distributed design information storing.

This contribution supports Objectives 6 and 7 -

- **Objective 6** - *Review past and current positions on the 'Project Memory' concept.*

A review of the literature on Organisational, Corporate and Project Memories, included in Chapters 2 and 8, indicated that Project Memories were influential in the early 1990s but since then work in this area, whilst valuable, has been limited due to a lack of high level guidance.

- **Objective 7** - *Make recommendations on criteria and content for a distributed-design Project Memory.*

  Greater understanding of the distributed information content stored by the students, at an early stage of the research, through the early descriptive studies has afforded the generation of a set of criteria for an effective Project Memory and guidance as to appropriate information content.

8.4 Reflection

Overall the experience of undertaking this PhD has been one of enlightenment, exasperation (at times) and fulfilment. The hardest aspect has been maintaining the momentum and continuity over the past seven years whilst also working fulltime as an academic. One of the reasons for carrying out the PhD, besides the production of this thesis, was to achieve personal academic development within a focussed area of expertise, namely Global Design and Engineering Design Education. This has been achieved through increased knowledge of the subject area and most importantly through the development of a network of academics in the field, meeting up annually at conferences and workshop events. The PhD journey has also enabled the development of research skills, greatly expanding methodological repertoire and evaluation skills.

Reflecting on the work itself, the *Principles for d-DIS* were positively received by both students and staff, who saw them as being useful in supporting distributed information storing and global design project work. The contribution made is capable of practical application in both class project work and potentially in industry. However, the author considers that in future work greater emphasis needs to be placed on the Principles, with project activity interventions which require teams to reflect more deeply on their stored information during distributed project work.

Limitations to the Work

Firstly, there was the possible impact of the author and researcher as a class tutor thereby presenting a potential conflict of interest. Every effort was made to minimise this as outlined earlier, for example, descriptive case studies and the content analysis of archived data and documents were chosen as the main research methods to identify influencing factors without having an effect on the processes being studied. No preferential treatment was given to students for taking part in the research study, with the author recognising the importance of clear boundaries as a class tutor and researcher. The students were unaware of the identity of the chosen case studies. Only the participants of the studies, interviews and focus groups were made clear as to why the study was being carried out; what was being studied; how information was being collected and what was to be done with the information.

Secondly, there were differences across the case studies, for example, the numbers of students carrying out the Global Design Project; the different nationalities at the remote sites across Study 1, 2 and 3; the different tasks offered to student teams; and the different software and hardware systems available to the distributed teams. Wherever possible effort was made to keep the variables to a minimum, but as interest in the Global Design Class increased class sizes, and as technologies developed, year-on-year improvements had to be made to the class. These are issues which have to be accounted for in any study in an educational context particularly when addressing studies involving technology over a period of time; in this case 3 years for the descriptive studies.

Thirdly, in order not to compromise the academic integrity of the UK class and the experience gained by participating students the decision was taken not to have control groups. Differences across studies and the absence of control groups can contribute to a lack of benchmarking and also make it difficult to later compare across studies. However, through the in-depth descriptive studies undertaken as part of the thesis, a list of five criteria have been developed for Project Memories and a series of ‘survey-style’ questions proposed to measure the success of the Principles. This will strongly support future research work in the areas of Project Memories and Principles. On reflection the author would propose the adoption of a tool such as a Confidence Log (LTDI, 1999) as a simple visual benchmark and feedback measurement tool. This would be of great benefit to students who could indicate their confidence with the Principles on a scale of 1-5. Such values would then be mapped to a graph to be shared with the class. These logs could also be used to self-monitor students' adoption and acceptance of the Principles as information storing activities on distributed project work progress. Fourthly, research studies involving student sample groups can often be problematic. UK engagement in project work seemed higher than remote partner engagement. This could have been partly due to familiarity with the researcher but was more likely due to the integration of assessment requirements within the Global Design Project for Strathclyde students, which was not the case for other students. The UK students were also willing to engage more in the related thesis work, although at times their availability restricted the numbers able to take part. This made the collection of data and the organisation of focus groups at times complex. Having f2f (real-time) access to students at only one location (U.K.) was also limiting at times. Students at far side locations (USA, Swinburne and Malta) were more often than not, only contactable via email. This limited opportunities for deeper engagement with these students. Reduced engagement was evident at times from remote sides during the Global Design Project work. This could be seen in the Swinburne collaborations where Swinburne students were weeks away from graduating and were thus less able to engage and contribute as much as they might otherwise have done. UK students were found to contribute most to the collaborative experience, in part due to the academic credit they would receive form their reflective reports. The USA, Swinburne and Maltese students, while fully involving themselves in the global design experience, made slightly less contributions rewarded only by participatory credit. Finally, there are associated limitations encountered in managing distributed research studies, not least of which was an inability to follow up questionnaire responses due to remote questionnaire participants at times failing to respond to emails. In such cases it took longer to receive confirmation of elements of research detail and to reach an understanding of meaning. Differing time zones and therefore availability tended to slow down progress. Students were often not available to take part in 'real-time' VC sessions which would have helped progress and supported understanding.

8.5 Future Work

This thesis focused on discovering how students stored information in distributed design project work and how a set of guiding Principles could support this. As a result of using the Principles students in distributed teams could produce a better Project Memory: comprehensive; centralised; organised and structured; containing both Formal and Informal information. A number of research opportunities have been identified from this work for further investigation which include –

Re-use of Project Memories in Education

Whilst this work has outlined the potential benefits of the use of a *Project Memory* during distributed project work, it would also be valuable to further the work by undertaking detailed empirical research into the re-use of material stored in Project Memories. PMs can provide a rich repository from which, lessons can be learnt; reusable learning objects can be harvested; and opportunities for reflection can be afforded. Following distributed project work, the PM acts as a digital repository, the content of which can be shared and re-used as good and poor exemplars for use in future Global Design Classes and indeed other classes. Good exemplars will set goals for students to exceed. Students can also reflect on and learn from poorer exemplars and from the failures of others who have previously experienced distributed design information management in global project work.

Trial the Principles on Longer Projects

Time was cited as a factor for the poor management of information on several of the Global Design Projects. Implementation of the Principles in longer distributed projects would afford a more robust assessment of the impact of the Principles on the success of distributed design information storing practices. In this situation a PM would become more of a necessity and more time would be available for interventions involving deeper reflection on the stored information.

Further Comparative Studies towards an Evaluation of Student Learning

Further studies could be undertaken which allow the systematic comparison between distributed projects. This would take a more 'experiment-style' approach ensuring that the differing number of variables in the study are kept to a minimum. This would afford the researcher greater control over the study and enable the identification of impacting factors. Five key criteria for a good Project Memory have now been identified and these could be implemented as a benchmarking system. These measures of success are: a centralised information store with all systems integrated or linked; at least equal amounts of Informal information as Formal information to give the 'richness' and context needed for stored distributed information; a comprehensive record of the project 'story' which is shown to support the decisions taken by distributed teams; that the information is stored frequently in order to keep everyone aware of project development and outcomes; and, finally that the Project memory is organised and structured in order that information can be accessed easily and quickly. Studies of this nature would then lend themselves to the evaluation of student learning using such a method as Kirkpatrick's 4 levels of Learning Evaluation: evaluating students' reaction, learning and behaviour and the results (Kirkpatrick, 2007).

Understanding of the Relationship between Project Memory and Project Output

The thesis showed that even with minimum intervention the application of the set of Principles for distributed-design information had an impact on a Project Memory, producing a more organised and structured, centralised and comprehensive Project Memory containing equal amounts of Formal and Informal information. The next logical step in the research would be to investigate the relationship between a good Project Memory and the output of the project task undertaken by the global student teams. Of course this would not be without its difficulties due to the complexity of the design and the number of contributing variables which could impact on the resulting final solution. As mentioned earlier in the thesis a good Project Memory cannot guarantee a good project outcome.

In final conclusion, interest in Principles and Project Memories from educators and programme planners in response to papers presented at conferences, has been high, indicating that there is merit in the revival of the *Project Memory Concept*; and an appetite for the use of a *set of guiding Principles for d-DIS* to support an effective *Project Memory*. Whilst this work focused on distributed design studies in an educational context it will also have benefit to those in industry.

Studies in industry and practice

This thesis examined the information stored by students during distributed design project work. Whilst the conditions for participating in global design in an educational context, were as closely as possible, mapped to those undertaken in an industrial setting, it is considered important that the research methods are developed and employed directly within an industrial context. Determining the value of applying the Principles within industry and the adoption of the Project Memory Concept and Model will also be also an important aspect of future work. Conceptual and empirical understanding of distributed teams in industry and practice are still underdeveloped. Theories and models are few (Cramton & Weber 2005). With the move in industry to globalisation and a more knowledge-intensive environment both the Principles and Project Memories have a lot to offer, but currently they lack empirical backing in an industrial context.

Grierson, H., Nicol, D., Littlejohn, A. & Wodehouse, A., 2004. Structuring and sharing information resources to support concept development and design learning. In: Proceedings of *The Network Learning Conference*, 5-7 April, Lancaster University, pp.572-579.

Grierson, H., Wodehouse, A., Ion, W., Juster, N.P., 2005. Supporting reflection and problem-based learning through the use of LauLima. In: Proceedings of *The International Engineering and Product Design Education Conference '05*, Napier University, Edinburgh, 15-16 September.

Grierson, H., Ion, W. & Juster, N., 2006. Project memories: Documentation and much more for global team design. In: Proceedings of *The International Engineering and Product Design Education Conference '06*, 7-8 September, Salzburg, Austria.

Grierson, H. and Ion, W., 2008. Distributed Design Information & Knowledge: Storage and Strategy. In: Proceedings of *The International Engineering and Product Design Education Conference* '06, 4-5 September, Barcelona.

Grierson, H., & Ion, W.J., 2009. Towards a set of principles for distributed-design information storing. In: Proceedings of *The International Conference on Engineering Design, ICED '09*. 24-27 August. Stanford University, Stanford, C.A., USA.

Ion, W.J., Wodehouse, A., Juster, N.P, Grierson, H., Stone, A., 2004. Educating the global designer. In Conference Proceedings of *EASED 2004*, Xi'An, China, 19-21 April 2004.

Nicol, D. J., Littlejohn, A. & Grierson, H., 2005. The importance of structuring information and resources within shared workspaces during collaborative design learning. *Open Learning Journal*, 20(1), pp.31-49.

Wodehouse, A., Grierson, H., Ion, W.J., Juster, N., 2006. Student searching behaviour in a digital library. In: Proceedings of *The International Engineering and Product Design Education Conference '06*, 7-8 September, Salzburg, Austria.

Wodehouse, A., Breslin, C., Eris, O., Grierson, H., Ion, W., Jung, M., Leifer, L., Mabogunje, A., Sonalkar, N., 2007. A reflective approach to learning in a global design project. In: Proceedings of *The International Engineering and Product Design Education Conference '07*, Northumbria University, Newcastle, UK, 13-14, September.

Adams, R. S., Turns, J. & Atman, C., 2003. What Could Design Learning Look Like?' In N. Cross & E. Edmonds, eds. *Expertise in Design, Creativity and Cognition Press*. University of Technology, Sydney, Australia.

Ahmed, S., Blessing, L.S. & Wallace, K.M., 1999. The relationships between data, information and knowledge based on a preliminary study of engineering designers. In: Proceedings of *DETC'99, ASME 1999 Design Engineering Technical Conferences and Computers and Information in Engineering Conference,* Las Vegas, Nevada, 12-15 September.

Ahmed, S., 2001. *Understanding the Use and Reuse of Experience in Engineering Design*. Ph.D. Thesis, Cambridge University, Cambridge, UK.

Ahmed, S. & Wallace, K., 2002. *Issues of Carrying out Empirical Research in Industry*. EDC, Engineering Department, Cambridge University.
Available at: http://redigering.sitecore.dtu.dk/upload/institutter/ipl/sektioner/2002edcpaperkmw.pdf (accessed 9 June 2010).

Ahmed, S., 2007. Empirical research in engineering practice. *Journal of Design Research*. (6) 3, pp.359-380.

Allard, S., Levine, K. & Tenopir, C., 2009. Design engineers and technical professionals at work: Observing information usage in the workplace. *Journal of the American Society for Information Science and Technology*, 60(3), pp.443-454.

Ardichvil, A., Page, V. & Wentling, T., 2003. Motivation and barriers to participation in virtual knowledge sharing communities of practice. *Journal of Knowledge Management*, 7(1), pp.64-77.

Arnison, L., & Miller, P., 2002. Virtual teams: A virtue for the conventional team. *Journal of Workplace Learning*, 14(4), pp.166-173.

Baird, F., Moore, C.J., Jagodzinski, A.P., 2000. An ethnographic study of engineering design teams at Rolls-Royce Aerospace. *Design Studies*, 21(4), pp.333-355.

Bannon, L. & Kuutti, K., 1996. Shifting perspectives on organizational memory: From storage to active remembering. In the Proceedings of *The 29th IEEE HICSS, 1996*, 3. IEEE Computer Society Press, pp156-167.

Bannon, L. & Bodker, S., 1997. Constructing Common Information Spaces. In: Proceedings of *The fifth conference of European Conference on Computer-Supported Cooperative Work*. Lancaster, UK, pp 81–96.

Baya, V., 1996. *Information handling behaviour of designers during conceptual design: Three experiments.* PhD Thesis. Stanford University, Palo Alto, CA, USA.

Bellinger, G., Durval, C. & Mills, A., 2004. Data, Information, Knowledge and Wisdom. Systems Thinking. Available at: http://www.systems-thinking.org/dikw/dikw.htm (Accessed 24 June 2010).

Benyon, D., 1990. *Information and data modelling.* Henley-on-Thames UK: Alfred Waller Ltd.

Berlin, L.M., .Jeffries, R., O'Day, V.L., Paepke, A. & Wharton, C., 1993. Where Did You Put It? Issues in the Design and Use of a Group Memory. In: Proceedings of *The INTERACT '93 and CHI '93 conference on Human Factors in computing systems.* Amsterdam, Netherlands, pp.23-30, New York, ACM.

Blaxter, L., Hughes, H. & Tight, M., 1996. *How to Research.* Buckingham, UK & Philadelphia, PA, USA: Open University Press.

Blessing, L.T.M., Chakrabarti, A., Wallace, K.M., 1998. *An overview of descriptive studies in relation to a general design research methodology* In E., Frankerberger, P., Badke-Schaub, & H., Birkhofer, (eds.) *Designers: The Key to Successful Product Development.* Springer, London, pp.42-56.

Blessing, L. T. M., Chakrabarti, A. & Wallace, K.M., 2009. *DRM, a Design Research Methodology*. Springer Dordrecht Heidelberg, London, New York.

Bohemia, E. & Roozenburg, N., 2004. Working collaboratively in today's global environment; a global product development course? In: Proceedings of *The International Engineering and Product Design Education Conference '04*, Delft Technical University, the Netherlands, 2-3 September.

Bohemia, E. & Harman, K., 2008. Globalization and Product Design Education: The Global Studio. *Design Management Journal*, 3(2), pp.53-68.

Bohemia, E., Harmam, K. & Lauche, K., 2009. *The Global Studio: Linking Research, Teaching and Learning. Research in Design Series*, 5, Amsterdam, IOS Press.

Bondarenko, O., & Janssen, R., 2005. Documents at hand: Learning from paper to improve digital technologies. In: Proceedings of *The SIGCHI conference on Human factors in computing systems*. ACM Press: Portland, Oregon, USA, pp.121-130.

Boston, O., 1998. *Technical liaisons in engineering design understanding by modelling*. Ph.D. Thesis, University of Bath, UK.

British Standards Institution, 2003. *Knowledge Management Vocabulary, BS PD7500,* British Standard Institution, London, UK.

Broadbent, J.A. & Cross, N., 2003. Design Education in the Information Age. *Journal of Engineering Design*, 14(4), pp.439-446(8).

Bronfenbrenner, U., 1976. The experimental ecology of education. *Teachers College Record*, 78(2), pp.157-178.

Bruce, C., 1997. *The Seven Faces of Information Literacy.* Auslib Press: Adelaide.

Bryman, A., 2004. *Social Research Methods,* 2nd Edition, Oxford: Oxford University Press.

Bucciarelli, L., 1984. Reflective practices in engineering design. *Design Studies*, 5(3), pp.185-190.

Bucciarelli, L., 1988. An ethnographic perspective on engineering design. *Design Studies*, 9(3), pp.159-168.

Bucciarelli, L., 1994. *Designing Engineers*. MIT Press: Cambridge, MA.

Caldwell, N.H.M., McMahon, C.A., Darlington, M.J., Heisig, P., Holburn, D.M. & Clarkson, P.J., 2009. Applying Engineering Information Management Principles to Microscopy. *Microscopy and Microanalysis*, 15(Suppl. 2), pp.806-807, Cambridge University Press.

Carmel, E., 1999. *Global software teams: collaborating across borders and time zones.* Upper Saddle River, NJ: Prentice Hall.

Chaffey, D. & Wood, S., 2004. *Business Information Management, Improving Performance Using Information Systems*. Harlow: Financial Times Prentice Hall.

Chickering, A.W. & Gamson, Z.F., 1991. *Applying the seven principles of good feedback practice in undergraduate education.* Jossey-Bass: San Francisco.

Choo, C.W., 1995. *Information Management for an Intelligent Organization: The Art of Environmental Scanning.* Medford, NJ: Learned Information.

Choo, C.W., 1996. The Knowing Organization: How organizations use information to construct meaning, create knowledge and make decisions. *International of Journal of Information Management,* 16(5), pp.329-340.

Choo, C. W., Detlor, B., & Turnbull, D., 2000. *Web Work: Information Seeking and Knowledge Work on the World Wide Web.* Dordrecht: Kluwer Academic Publishers.

Chudoba, K.M., Wynn, E., Lu, M. & Watson-Manheim, M.B., 2005. How Virtual are we? Measuring virtuality and understanding its impact in a global organization. *Information Systems Journal*, 15(4), pp. 279-306.

Clark, K. & Fujimoto, T., 1991. *Product Development Performance.* Boston, MA: Harvard Business School Press.

Coates, G., Duffy, A.H.B., Whitfield, I., & Hills, W., 2004. Engineering management operational design coordination. *Journal of Engineering Design.* 15(5), pp.433-446.

Conklin, E.J., 1992. Capturing Organizational Memory, in Proceedings of *The GroupWare'92 Conference,* D. Coleman, ed. San Mateo, CA: Morgan Kaufmann, pp. 133-137.

Conklin, E.J., 2001. *Designing Organizational Memory: Preserving Intellectual Assets in a Knowledge Economy*. Group Decision Support System, Inc.
Available at: http://cognexus.org/dom.pdf (accessed 2 July, 2010).

Conway, A. P., Giess, M.D., Lynn, A., Ding, L., Goh, Y.M., MacMahon, C.A. & Ion, W.J., 2008. Holistic Engineering Design: A Combined Synchronous and Asynchronous Approach. *ASME International Design Engineering Technical Conference, Computers and Information in Engineering Conference,* (IDETC/CIE 2008). Brooklyn, New York, USA, 3-6 August.

Court, A.W., Culley, S.J. & McMahon, C.A., 1993. *A survey of information access and storage amongst engineering designers*. The University of Bath, UK.

Court, A.W., 1995. *The modelling and classification of information for engineering designers*. PhD Thesis, University of Bath, UK.

Court, A.W., 1997. The Relationship Between Information and Personal Knowledge in New Product Development. *International Journal of Information Management,* 17(2), pp.123-138.

Court, A.W., Culley, S.J. & McMahon, C.A., 1997. The influence of information technology in new product development: Observations of an empirical study of the access of engineering design information. *International Journal of Information Management,* (17)5, pp 359-375.

Cowan, J., 1998. *On becoming an innovative university teacher: reflection in action.* London: SRHE & Open University Press.

Crabtree, R. A., Fox, M.S. & Baid, N.K., 1997. Case studies of coordination activities and problems in collaborative design. *Research in Engineering Design,* 9(2), pp.70-84.

Cramton, C.,D., 2001. The mutual knowledge problem and its consequences for dispersed collaboration. *Organisation Science,* 12(3), pp.346-471.

Cramton, C.D. & Orvis, K.L, 2003. Overcoming the barriers to information sharing in virtual teams. Chapter 10 in C.B. Gibson, & S.G. Cohen, *Virtual teams that work: Creating conditions for virtual team effectiveness*. San Francisco: Jossey-Bass.

Cramton, C.D. & Webber, S.S., 2005. Relationships among geographic dispersion, team processes and effectiveness in software development teams. *Journal of Business Research.* 58(6), pp.758-765.

Cross, N. & Cross C.A., 1995. Observations of teamwork and social processes in design. *Design Studies*, 16(2), pp.143-170.

Cross, N. 2001. Design cognition: Results from protocol and other empirical studies of design activity. In C. Eastman, M. McCracken & W. Newstetter (eds.), *Design knowing and Learning: Cognition in Design Education*. Amsterdam: Elsevier, pp.79-103.

Cubranic, D. & Murphy, G., 2003. Hipikat: Recommending Pertinent Software Development Artifacts. In: Proceedings of *25th International Conference on Software Engineering (ICSE'03)*, Portland, Oregon. IEEE Computer Society, Washington DC, USA, pp.408-418.

Culley, S.J., Court, A.W. & McMahon, C.A., 1992. The information Requirements of Engineers Designers. *Engineering Designer*, 18(3), pp.21-23.

Culley, S. J., & Allen, R. D., 1999. Informal information - definitions and examples with reference to the electronic catalogue. In: Proceedings of *The International Conference on Engineering Design*, ICED '99. Munich, Germany, 24-26 August.

Culley, S. J., O. P. Boston and C. A. McMahon, 1999. Suppliers in new product development: Their information and integration. *Journal of Engineering Design*, 10(1), pp.59-75.

Curtis, D., 2001. *Start with the pyramid: Real-world issues motivate students*. Available at: http://www.edutopia.org/start-pyramid (accessed 6 July, 2010).

Daft, R. L., & Lengel, R. H., 1984. Information richness: A new approach to managerial behaviour and organisation design. In B.M. Straw & L.L. Cummings, eds. *Research In Organisational Behaviour*, 6, pp.191-233.

Davenport, T.H. 1993. *Process Innovation: Reengineering Work Through Information Technology*. Boston, MA: Harvard Business School Press.

Davenport, T.H. with Prusak, L., 1997. *Information Ecology*, Oxford: Oxford University Press.

Davenport, T.H. and Prusak, L., 1998. *Working Knowledge: How organizations manage what they know*. Harvard Business School Press, Boston.

Davenport, T.H. & Marchand, D., 1999. Is KM just good information management? *Information Management*, 6(2), pp.91-100.

Davis, J., Subrahmanian, E., Konda, S., Granger, H., Collins, M. & Westerberg, A., 2001. Creating shared information spaces to support collaborative design work. *Information Systems Frontiers, Special Issue: Information Systems Frontiers on Workflow*, 3(3), pp.377-392.

De Corte, E., 1999. New perspectives on learning and teaching in higher education. In A. Burgen, ed. *Goals and purposes of higher education in the twenty-first century*. London: Jessica Kingsley Publishers.

de la Garza, J. M. and Oralkan G. A., 1995. Using design intent for interpreting brand-name or equal specification. *Journal of Computing in Civil Engineering*, 9(1), pp.43-56.

Demian, P. and Fruchter, R., 2004. *CoMem: Evaluating interaction metaphors for knowledge reuse from a corporate memory*. Stanford University, Center for Integrated Facility Engineering, CIFE TR158. Available at: http://cife.stanford.edu/online.publications/TR158.pdf (accessed 3 July 2010).

Denard, H., 2003. E-tutoring and transformations in online learning. *Interactions*, 7(2), School of Theatre Studies, University of Warwick.

Denzin, N., 1978. *Sociological methods: A source book* (2nd edition). New York: McGraw-Hill.

Dillenbourg, P., 1999. Introduction: What is meant by collaborative learning? In P. Dillenbourg, ed., *Collaborative learning: cognitive and computational approaches.* Oxford: Elsevier, pp.1-19.

Driskell, J. E., Radtke, P. H., & Salas, E., 2003. Virtual teams: Effects of technological mediation on team performance. *Group Dynamics: Theory, Research, and Practice*, 7(4), pp.297–323.

Duarte, D. L., & Snyder, N. T., 1999. *Mastering virtual teams*. San Francisco: Jossey-Bass.

Easterby-Smith, M., Thorpe, R. & Lowe, A., 2001, *Management Research: An Introduction.* SAGE Series in Management Research, 2nd edition.

Eastman, C.M., 1970. On the analysis of intuitive design processes. G. T. Moore, ed. *Emerging methods in environmental design and planning*, Cambridge, MA: MIT Press.

Eastman, C., 2001. Design cognition: Results from protocol and other empirical studies of design activity. Chapter 5 in C. M. Eastman, W. M. McCracken, & W. C. Newstetter, eds., *Design Knowing and Learning: Cognition in Design Education.* Amsterdam: Elsevier.

Elspass, W.J. & Holliger, C., 2004. Design education via collaboration in advanced knowledge environment. In: Proceedings of *The International Engineering and Product Design Education Conference '04*, Delft University of technology, the Netherlands, 2-3 September, 2004.

Fidel, R., Bruce, H., Peitersen, A.M., Durnais, S., Grudin, J. & Poltrock, S., 2000. Collaborative information retrieval. *The New Review of Information Behaviour Research*, 1(1), pp.235-247.

Foltz, C., Schmidt, L. & Luczak, H., 2002. Not seeing the woods for the trees – Empirical studies in engineering design. *Workshop on the Role of Empirical Studies in Understanding and Supporting Engineering Design*, NIST, Gaithersburg, MD.

Frankfort-Nachmias, C. & Nachmias, D., 1996. *Research Methods in the Social Sciences.* 5th edition. London: Arnold, pp.599.

Fricke, G., 1993. Empirical investigations of successful approaches when dealing with differently précised design problems. In: Proceedings of *The International Conference on Engineering Design, ICED '93*. 17-19 August, Heurista, Zurich.

Fricke, G., 1996. Successful individual approaches in engineering design. *Research in engineering design*, 8(3), pp.151-165.

Fruchter, R. & Yen, S., 2000. RECALL in Action. In the proceedings of *ASCE ICCCBE-VIII Conference*, R. Fruchter, K. Roddis & F. Pena-Mora, eds., Stanford, CA, 14-16 August, pp.1012-1021.

Fruchter, R., & Demian, P., 2002. Knowledge Management for Reuse. In: Proceedings of *The CIBw78 Conference 2002, Distributing Knowledge in Building*, 1. The Aarhus School of Architecture, Denmark, pp.93-100.

Ganguli, A., & Mostashari A., 2008. Virtual Teams: An overview of the literature. *COMPASS Working Paper Series WPS 2008-03,* May 2008.

Gibbs, G. & Simpson, C., 2004. Conditions under which assessment supports students' learning. *Learning and Teaching in Higher Education*, 1(1), pp.3-31.

Gibson, C. B., & Cohen, S. G., 2003. *Virtual teams that work: Creating conditions for virtual team effectiveness.* San Francisco: Jossey-Bass.

Grierson, H., Nicol, D., Littlejohn, A. & Wodehouse, A., 2004. Structuring and sharing information resources to support concept development and design learning. In: Proceedings of *The Network Learning Conference,* 5-7 April, Lancaster University, pp.572-579.

Grierson, H., Wodehouse, A., Ion, W., Juster, N.P., 2005. Supporting reflection and problem-based learning through the use of LauLima. In: Proceedings of *The International Engineering and Product Design Education Conference '05,* Napier University, Edinburgh, 15-16 September.

Grierson, H., Ion, W. and Juster, N., 2006. Project memories: Documentation and much more for global team design. In: Proceedings of *The International Engineering and Product Design Education Conference '06,* 7-8 September, Salzburg, Austria.

Grierson, H., & Ion, W.J., 2009. Towards a set of principles for distributed-design information storing. In: Proceedings of *The International Conference on Engineering Design, ICED '09*. 24-27 August. Stanford University, Stanford, C.A., USA.

Gross, M.D., Do, E.Y.L., McCall, R.J, Citrin, W.V., Hamill, P., Warmack, A.& Kuczun, K.S., 1997. Collaboration and coordination in architectural design: approaches to computer-mediated work, *TeamCAD Symposium on collaborative CAD,* Design Machine Group, University of Washington, Seattle, 12-13 May, pp.17-24.

Guba, E. G., & Lincoln, Y. S., 1981. *Effective evaluation: Improving the usefulness of evaluation results through responsive and naturalistic approaches*. San Francisco, CA: Jossey-Bass.

Hales, C., 1987. *Analysis of the engineering design process in an industrial context.* PhD Thesis, Department of Engineering Science, Cambridge University, UK.

Hales, C., 1993. *Managing Engineering Design*. Harlow, UK: Longman.

Henderson, K, 1999. *On Line and On Paper*. MIT Press, Cambridge MA, USA.

Herbsleb, J.D., Mockus, A., Finholt, T.A., & Grinter, R.E., 2000. Distance, dependencies, and delay in a global collaboration. In: Proceedings of *ACM Conference on Computer-Supported Cooperative Work*, Philadelphia, PA, 2-7 December, pp.319-328.

Herbsleb, J.D., & Mockus, A., 2003. Formulation and preliminary test of an empirical theory of coordination in software engineering. In: Proceedings of *European Software Engineering Conference and ACM SIGSOFT Symposium on the Foundations of Software Engineering*, Helsinki, Finland, 1-5 September, pp. 112-121.

Herbsleb, J.D., 2007. Global software engineering: The future of socio-technical coordination. *Future of software engineering FOSE '07*, Minneapolis, USA, May 2007, pp.188-198.

Herder, E. Sjoer, 2003.Group-based learning in internationally distributed teams: an evaluation of a cross-Atlantic experiment. In: Proceedings of *33rd Annual Frontiers in Education (FIE'03),* 3, Boulder, CO, USA.

Heriott, R.E., & Firestone, W.A., 1983. Multisite qualitative policy research: Optimizing description and generalizability. *Educational Researcher* 12(3), pp.14-19.

Hertel, G., Geister, S. & Konradt, U., 2005. Managing virtual teams: A review of current empirical research. *Human Resource Management Review,* 15 (1), pp.69-95.

Hertzum, M. & Pejtersen, A.M., 2000. The information-seeking practices of engineers: searching for documents as well as for people. *Information Processing and Management*, 36(5), pp.761-778.

Hicks, J., 1993. *Management information systems: A user perspective*. MN, USA: West Publishing Company.

Hicks, B.J., Culley, S.J., Allen, R.D. & Mullineux, G., 2002. A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design. *International Journal of Information Management*, 22, pp.263-280.

Hicks, B. J., Culley, S.J. & McMahon, C.A., 2006. A study of issues relating to information management across engineering SMEs. *International Journal of Information Management*, 26 (4), pp. 267-289.

Hicks, B., 2007. Lean information management: Understanding and eliminating waste. *International Journal of Information Management*, 27(4), pp.233-249.

Hicks, B.J., Dong, A., Palmer, R. & McAlpine, H.C., 2008. Organizing and managing personal electronic files: A mechanical engineer's perspective. *ACM Transactions on Information Systems*, 26(4), pp.1-40.

Hinds, P.J.& Weisband, S.P., 2003. Knowledge Sharing and Shared Understanding in Virtual Teams. Chapter 2 in C.B. Gibson, & S.G. Cohen, *Virtual teams that work: Creating conditions for virtual team effectiveness*. San Francisco: Jossey-Bass.

Hinds, P. & Mortensen, M., 2005. Understanding conflict in geographically distributed teams: The moderating effects of shared identity, shared context, and spontaneous communication. *Organisational Science*, 16(3), pp.290-307.

Hoegl, M., Ernst, H. & Prosperio, L., 2007. How teamwork matters more as team member dispersion increases. *The Journal of Product Innovation Management*, 24(2), pp.156-165.

Holden, C., 2003. Learning repositories summit: initial research summary. *Advanced Distributed Learning Summit*, University of Wisconsin, Madison.
Available at: http://www.academiccolab.org/resources/RepositoryPaper.pdf (Accessed 1 July, 2010).

Holton, J.A., 2001. Building trust and collaboration in a virtual team. *Team Performance Management*, 7 (3-4), pp.36-47.

Huber, G.P., 1991. Organizational Learning: The contributing processes and the literature. Organization Science, 2(1). Special Issue: Organizational Learning: Papers in Honor of (and by) James G. March (1991), pp.88-115.

Huet, G., 2006. *Design transaction monitoring: Understanding design reviews for extended knowledge capture.* PhD Thesis, University of Bath, UK.

Ion, W.J. & Neilson, A.I., 1997. The use of shared workspaces to support the product design process. In S. Ganesan & B. Prasad, eds., *Advances in concurrent engineering* **-** *CE97*, Lancaster, Penn., USA: Technomic Publications, pp.207-212.

Ion, W.J., Wodehouse, A., Juster, N.P, Grierson, H., Stone, A., 2004. Educating the global designer. In Conference Proceedings of *EASED 2004*, Xi'An, China, 19-21 April 2004.

Jagodzinski, P., Reid, F.J.M., Culverhouse, P., Parsons, R. & Phillips, I., 2000. A study of electronics engineering design teams. *Design Studies*, 21(4), pp.375-402.

Jarvenpaa, S., Knoll, K., & Leidner, D., 1998. Is anybody out there? Antecedents of trust in global virtual teams. *Journal of Management Information Systems* 14(4), pp.29-64.

Jarvenpaa, S. L., & Leidner, D. E., 1999. Communication and trust in global virtual teams. *Organization Science*, 1, pp.791–815.

Johanson, M. & Törlind, P., 2004. Mobility support for distributed collaborative teamwork. *Electronic Journal of Information Technology in Construction*, 9, pp.355-366.

Jonassen, D.H. & Carr, C.S., 2000. Mindtools: Affording multiple knowledge representations for learning. In S.P. Lajoie, ed., *Computers as Cognitive Tools.* Mahwah, NJ: Lawrence Erlbaum Associates, pp.165-196.

Kerins, G., Madden, R., & Fulton, C., 2004. Information seeking and students studying for professional careers: the cases of engineering and law students in Ireland. *Information Research*, 10(1), paper 208. Available at: http://InformationR.net/ir/10-1/paper208.html (accessed 6 July 2010).

Kiesler, S. & Cummings, J.C., 2002. What do we know about proximity and distance in work groups? A legacy of research. In: P.J. Hinds & S. Kiesler, editors, *Distributed work*, Cambridge, MA: MIT Press, pp.57-82.

Kirkpatrick, D.L., 2007. The Four Levels of Evaluation: Measurement and Evaluation. Infoline. Issue 0701. ASTD Press.

Kogut, B. & Zander, U., 1992. Knowledge of the Firm. Combinative Capabilities, and the Replication of Technology, *Organization Science*, 3(3), pp.383-397.

Kolb, D., 1984. *Experiential Learning: on the science of learning and development.* San Francisco: Jossey-Bass.

Konda, S., Monarch, I., Sargent, P., Subrahmnian, E., 1992. Shared memory in design: A unifying theme for research and practice. *Research in Engineering Design*, 4(1), pp.23-42.

Kotlarsky, J. and Oshri, l., 2005. Social ties, knowledge sharing and successful collaboration in globally distributed system development projects. *European Journal of Information Systems*, 14(1), pp.37-48.

Krippendorff. K.H., 2004. *Content analysis: An introduction to its methodology* (2nd edition). Thousand Oaks, CA: Sage Publications.

Kumar, K., van Fenema, P.C. & Von Glinow, M.A., 2005. Intense collaboration in globally distributed work teams: Evolving patterns of dependencies and coordination. In D.J. Shapiro, M.A. von Glinow & J.L.C. Cheng, editors, *Managing multinational teams: Global Perspectives.* Oxford: Elsvier, pp.127-154.

Lauche, 2007. Empirical research on information and knowledge management in designing: where are we and where do we go from here? *Journal of Design Research.* (6)3, pp.295-310.

LTDI, 1999. Evaluation Cookbook, Learning Technology Dissemination Initiative. Available at: http://www.icbl.hw.ac.uk/ltdi/cookbook/confidence_logs/reference.html (accessed 16 August 2010).

LeCompte, M.D. & Goetz, J.P., 1983. *Playing with ideas: Analysis of qualitative data.* Paper presented at the Annual Meeting of the American Educational Research Association. April, Montreal, Canada.

Leifer, L.J., 1991. Instrumenting the design process. In: Proceedings of *The International Conference on Engineering Design, ICED '91*. Zurich, Switzerland, 27-29 August.

Lewis, R., 1998. Membership and management of a `virtual' team: The perspectives of a research manager. *R & D Management*, 28(1), pp.5-13.

Lincoln, Y.S. & Guba, E.G., 1985. *Naturalistic Enquiry.* Beverley Hills, CA: Sage.

Lipnack, J., & Stamps, J., 1997. *Virtual teams.* New York: John Wiley.

Lloyd, P.A., 2000. Storytelling and the development of discourse in the engineering design process. *Design Studies*, 21(4), pp.357-373.

Lojeski, K. S., Reilly, R., & Dominick, P., 2006. The role of virtual distance in innovation and success. In: Proceedings of *The 39th Annual Hawaii International Conference on System Sciences, (HICSS '06).* Waikaloa, Hawaii, 4-7 January.

Lowe, A., McMahon, C.A., Culley, S.J., Coleman, P. & Dotter, M., 2003. A novel approach towards design information management within Airbus. In: Proceedings of *The International Conference on Engineering Design, ICED'03.* Stockholm, Sweden, 19-21 August.

Lowe, A, McMahon, C and Culley, S.J., 2004. Information access, storage and use by engineering designers, Part 1. *Engineering Designer*, 30 (2), pp.30-32.

MacGregor, S.P., 2002. *Describing and supporting the distributed workspace: Towards a prescriptive process for design teams*. PhD Thesis, The University of Strathclyde, Glasgow, UK.

MacGregor, S.P., 2004. Using the case study method to study distributed design. In E. Subrahmanian, R. Sriram, P. Herder, H. Christiaans & R Schneider, eds. *Workshop Proceedings: The Role of Empirical Studies in Understanding and Supporting Engineering Design*, Delft University Press, pp.18-29.

Malhotra, A., Majchrzak, A., Carman, R., & Lott, V., 2001. Radical innovation without collocation: A case study at Boeing-Rocketdyne. *MIS Quarterly,* 25(2), pp.229-249.

Marsh, J. R., 1997. *The capture and utilisation of experience in engineering design*. PhD Thesis, Cambridge University, Cambridge, UK.

Martins, L.L., Gilson, L.L. & Maynard, M.T., 2004. Virtual teams: What do we know and where do we go from here? *Journal of Management*, 30(6), pp.805-835.

McAlpine, H., Hicks, B. J., Huet, G. & Culley, S.J., 2006. An Investigation into the use and content of the engineer's logbook, *Design Studies*, 27(4), pp.481-504.

McAlpine, H., Hicks, B.J., Culley, S.J., 2009, Comparing the information content of formal and informal design documents: Lessons for more complete design records. *International Conference on Engineering Design, ICED'09.* 24-27 August, Stanford, CA, USA.

McDonough III, E F., Kahn, K B. & Barczak, G., 2001. Investigation of the use of global, virtual and collocated new product development teams. *Journal of Product Innovation Management*, 18(2), pp.110-120.

McMahon, C.A., Pitt, D.J., Yang, Y. & Sims Williams, 1993. Review: An information management system for informal design data. In: K. H. Law, ed. Proceedings of *The 1993 ASME Computer in Engineering Conference and Exposition,* San Diego, CA, pp.215-226.

McMahon, C.A., Pitt, D.J., Yang, Y. & Sims Williams. J.H., 1995. An information management system for informal design data. *Engineering with Computers*, 11, pp.123-135.

McMahon, C.A., 2002. Empirical Design Research: Fuzzy Glimpses of Practice. *Workshop on the Role of Empirical Studies in Understanding and Supporting Engineering DesignWork*, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA.

McMahon, C.A., Lowe, A. & Culley, S.J., 2004. Knowledge management in engineering design: personalization and codification. *Journal of Engineering Design*, 15(4), pp.307-325.

McMahon, C.A., Giess, M. & Culley, S.J., 2005. Information management for through life product support: the curation of digital engineering data. *International Journal of Product Lifecycle Management*, 1(1), pp.26-42.

McMahon, C.A., Caldwell, N., Darlington, M., Culley, S.J., Giess, M., Clarkson, J., 2009. *The development of a set of principles for the through-life management of engineering information.* Documentation, Bath, England: University of Bath, (kim40rep007mjd10).
Available at: http://opus.bath.ac.uk/16132/1/kim40rep007mjd10.doc (accessed 2 July 2010).

Megill, K.A. 1997. *Corporate Memory Information Management in the Electronic Age*. London: Bowker Saur.

Mekhilef, M., Bigand, M. & Bourey, J-P., 2005. Benefits of a Project Memory to Engineering Design. In: Proceedings of *The International Conference on Engineering Design, ICED '05*. Melbourne, Australia, 15-18 August.

Miles, M.B. & Huberman, A.M., 1994. *Qualitative data analysis: An expanded sourcebook.* 2nd ed. London: Sage & California: Thousand Oaks.

Mingers, J., 2007. Combining IS research methods: towards a pluralist methodology. *Information Systems Research*, 2(3), pp.240-259.

Minneman, S.L., 1991. *The social construction of a technical reality: Empirical studies of group engineering design practice*. PhD Thesis. Stanford, CA, USA. Xerox PARC report SSL-91-22.

Monticolo, D., Hilaire, V., Gomes, S., Koukam, A., 2008. A multi-agent system for building project memories to facilitate the design process. *Integrated Computer-Aided Engineering*, 15(1), pp.3-20.

Morgan, D.L. (1998) Planning Focus Groups, Thousand Oaks, California: Sage.

Morrison, J., 1993. Team memory: information management for business teams. In: Proceedings of *The 26th Annual Hawaii International Conference on System Sciences,* 4, January, 1993, pp.122-131.

Nicol, D.J. & MacLeod, I, A., 2004. Using a shared workspace and wireless laptops to improve collaborative project learning in an engineering design class. *Computers & Education*, 44(4), pp.559-575.

Nicol, D. J., Littlejohn, A. & Grierson, H., 2005. The importance of structuring information and resources within shared workspaces during collaborative design learning. *Open Learning Journal*, 20(1), pp.31-49.

Nicol, D.J. & Macfarlane-Dick, D., 2006. Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education*, 31(2), pp.199-218.

Nicol, D., 2007. Principles of good assessment and feedback: theory and practice. Keynote paper at *Assessment design for learner responsibility conference*, 29-31 May 2007. Available at: http://www.reap.ac.uk/reap07/Welcome/tabid/72/Default.html (accessed 4 July 2010).

Nonaka, I. & Takeuchi, H., 1995. *The knowledge creating company: How Japanese companies create the dynamics of innovation.* New York: Oxford University Press.

Oliver, R., 2001. Exploring the development of critical thinking skills through a web-supported problem-based learning environment. Chapter 8 in J. Stephenson, ed., *Teaching and learning online.* London: Kogan Page, pp.98-111.

Olson, J.S. & Olson, G.M., 2004. Culture surprises in remote software development teams. *Queue*, 1(9), pp.52-59.

Oppenheim, A. N., 1992. *Questionnaire Design, Interviewing and Attitude Measurement.* London: Pinter Publishers.

Oshri, I., van Fenema, P.C. & Kotlarsky, J., 2008. Knowledge transfer in globally distributed teams: the role of transactive memory. Chapter 2 in: J. Kotlarsky, Oshri, I. & P. van Fenema, editors, *Knowledge Processes in Globally Distributed Contexts.* London: Palgrave Macmillan, pp.24-52.

Pahl, G., & Beitz, W., 1996. *Engineering design - A systematic approach,* 2nd edition, London: Springer.

Perrenet, J.C., Bouhuijs, P.A.J. & Smits, J.G.M.M., 2000. The suitability of problem-based learning for engineering education: theory and practice. *Teaching in Higher Education*, 5(3), pp.345-358.

Perry, M., Fruchter, R. & Rosenberg, D., 1999. Co-ordinating distributed knowledge: an investigation into the use of an organisational memory. *Cognition, Technology and Work*, 1, pp.142-152.

Poltrock, S., Grudin, J., Durnais, S., Fidel, R., Bruce, H. & Pejtersen, A.M., 2003. Information Seeking and Sharing in Design Teams. In: Proceedings of *The 2003 International ACM SIGGROUP, Conference on Supporting Group Work*. Sanibal, FL, USA, pp. 239-247.

Powell, A., Piccoli, G., & Ives, B., 2004. Virtual teams: A review of current literature and directions for future research. *Database for Advances in Information Systems*, 35(1), pp.6-36.

Pugh, S., 1991. *Total Design: Integrated methods for successful product engineering.* Wokingham, UK: Addison-Wesley Publishers Ltd.

Quintus, P., 2000. Managing Knowledge: A Big Picture. Presented at *Routes into Knowledge Management*, City Information Group, Baltic Exchange, London, 11 October.

Radcliffe, D., & Lee, T.Y., 1989. Design methods used by undergraduate engineering students. *Design Studies*, 10(4), pp.199-207.

Ramage, M. and Reiff, F., 1996. *Links between Organisational Memory and Cooperative Awareness.* Available at: http://www.comp.lancs.ac.uk/computing/research/cseg/projects/evaluation/OM_CA.html (accessed 3 July, 2010).

Restrepo, J., Rodríguez, A., & Christiaans, H., 2000. The finality argument on design methods: A theoretical approach from the social sciences. In S. Pizzocaro, A. Arruda & D. de Moraes, eds. *Design Plus Research: Proceedings of the Politecnico di Milano Conference*. Politecnico di Milano: Milano, pp.109-115.

Roschelle, J.& Teasley, S.D.,1995. The construction of shared knowledge in collaborative problem solving. In C. O'Malley, ed., *Computer supported collaborative learning*, New York: Springer-Verlag.
Rosen, B., Furst, S., & Blackburn, R., 2007. Overcoming barriers to knowledge sharing in virtual teams. *Organizational Dynamics*, 36(3), pp.259-273.

Roy, R., Makri, C. & Kritsilis, D., 2004. Documenting technical specifications during the conceptualisation stages of aeroengine product development. In D. Marjanovic, ed. *8th International Design Conference*. Dubrovnik, Croatia, May 18-21, pp.897-902.

Rzevski, G., 1985. On criteria for assessing an information theory. *Computer Journal*, 28(3), pp.200-202.

Sarker, S. & Sahay, S., 2004. Implications of space and time for distributed work: An interpretive study of US-Norwegian system development teams. *European Journal of Information Systems*, 13(1), pp.3-20.

Sauter, C., Morger, O., Mühlherr, T., Hutchison, A. & Teufel, S., 1995. CSCW for Strategic Management in Swiss Enterprises: an Empirical Study. In Marmolin, H., Sundblad, Y. & Schmidt, K. (eds.), Proceedings of *The 4th Euoropean Conference on Computer-Supported Cooperative Work*, pp.117-132.

Schank, R.C., 1990. *Tell me a story: A new look at real and artificial memory.* New York: Scribner's Sons.

Schmidt, K & Bannon, L., 1992. Taking CSCW Seriously; Supporting Articulation Work.*Computer Supported Cooperative Work (CSCW)*, pp.7-40, Netherlands, Kluwer Academic Publishers.

Schon, D., 1983. *The Reflective Practitioner*. San Francisco: Jossey-Bass.

Sclater, N., Grierson, H., Ion, W.J. & MacGregor, S.P., 2001. Online collaborative design projects: Overcoming barriers to communication. *International Journal of Engineering Education*, 17(2), pp.189-196.

Shah, S. & Corley, K.G., 2006. Building better theory by bridging the quantitative-qualitative divide. *Journal of Management Studies,* 43(8), pp.1821-1835.

Shaikh, A.N. & Macauley, L., 2001. Integrating groupware technology into a learning environment, *Association for Learning Technology Journal*, 9(2), pp.47-63.

Sharifi, S. & Pawar, K.S., 2001. Product development strategies for agility. In A. Gunasekaran, ed. *Agile manufacturing: The 21st century competitive strategy*. Amsterdam: Elsevier, pp.175-192 (p.183).

Sheppard, K., Dominick, P. & Aronson, Z., 2004. Preparing engineering students for the new business paradigm of international teamwork and global orientation. *International Journal of Engineering Education*, 20(3), pp.475-483.

Sikkel, K., Gommer, L. and van der Veen, J., 2002. Using shared workspaces in higher education. *Innovations in Education and Teaching International*, 39(1), pp.26-45.

Skyrme, D., 1999. *Knowledge networking: creating the collaborative enterprise*. Oxford: Butterworth Heinemann.

Smith, P.G. & Blanck, E.L., 2002. From experience: leading dispersed teams. *The Journal of Production Innovation Management,* 19(4), pp.294-304.

Stenmark, D., 2001. The Relationship between Information and Knowledge. In: Proceedings of *IRIS 24*, Ulvik, Norway, August 11-14.

Subrahmanian, E., 1991. Notes on empirical studies of engineering tasks and environments. Invited position paper *in NSF Workshop on Information capture and access in engineering design environments*. Ithaca, New York, pp.567-578.

Subrahmanian, E., 1992. Notes on empirical studies of engineering tasks and environments. Position paper, in *NSF Workshop on Information Capture and Access in Engineering Design Environments.* Ithaca, NY, pp.567-578.

Subrahmanian, E. & Jellum, E., 1998. Information Flow Analysis for Information Technology Support. In *Total Plant Engineering, Internal Company Report*, ABB, Norway.

Suh, N.P., 1990. *Principles of Design.* Oxford, UK: Oxford University Press.

Tang, J.C., 1989. *Listing, drawing, and gesturing in design: A study of the use of shared workspaces by design teams.* Xerox PARC Technical Report SSL-89-3. Ph.D. Dissertation, Stanford University.

Tang, J. C., 1991. Findings from observational studies of collaborative work. *International Journal of Man-Machine Studies,* 34(2), pp.143-160.

Tang, L.C.M., Zhao, Y., Austin, S., Darlington, M. & Culley, S.J., 2008. Overload of information or lack of high value information: Lessons learnt from construction. In: Proceedings of *The 9th European Conference on Knowledge Management and Evaluation, ECKM 2008,* Southampton Solent University, Southampton, UK, September.
Available at: http://hdl.handle.net/2134/5090 (Accessed 2 July 2010).

Teufel, S., C. Sauter, T. Muhlherr & K. Bauknecht, 1995. *Computerunterstutzung fur die Gruppenarbeit*. Bonn: Addison-Wesley.

Thissen, M.R., Page, J.M., Bharathi, M.C. & Austin, T.L., 2007. Communication tools for distributed software development teams. In *Proceedings of the 2007 ACM SIGMIS CPR conference on Computer personnel research: The global information technology workforce.* ACM: New York, USA, pp.28-35.

Thomas, J.W., 2000. *A Review of Research on Project-Based Learning*. Ph. D Thesis. The AutoDesk Foundation, San Rafael, California, USA.
Available at: http://www.bie.org/index.php/site/RE/pbl_research/29 (accessed 4 July 2010).

Thompson, M. & Wiliam, D, 2007. Tight but loose: A conceptual framework for scaling up school reforms. Paper presented at the annual meeting of the *American Educational Research Association*, 19-13 April, Chicago, IL, USA.

Tomiyama, T., 1995. A design process model that unifies general design theory and empirical findings. *ASME Design Engineering*, 83(2), pp.329–340.

Tuomi, I., 1999. Data is more than knowledge: Implications of a reversed hierarchy for knowledge management and organizational memory. In: Proceedings of *The Thirty-Second Hawaii International Conference on Systems Sciences*, IEEE Computer Society Press, Los Alamitos, CA.

Ullman, J., Stauffer, L.A., & Dieterich, T., 1987. *Preliminary results of an experimental study of the mechanical design process.* Technical Report-856-30-9, Department of Computer Science, Oregon State University.

Ulrich, K.T. & Eppinger, S. D., 2004. *Product Design and Development.* Third Edition, Boston, MA: Irwin McGraw-Hill.

Valkenburgh, R. & Dorst, K., 1998. The reflective practice of design teams. *Design Studies*, 19(2), pp.249-271.

Van der Veen, J. & Collis, B., 1997. *Telematic Tools to Support Group Projects in Higher Education*. The University of Twente. Available at: http://doc.utwente.nl/fid/1314 (accessed 6 July, 2010).

Wall, R., 1986. *Finding and Using Product Information: from trade catalogues to computer systems.* Aldershot, Hants., Brookfield, VT: Gower.

Wallace, K.M., Ahmed, S. & Bracewell, R.H., 2005. Engineering Knowledge Management. In P.J. Clarkson & C.M. Eckert, eds. *Design Process Improvement; a current review of practice.* London: Springer-Verlag, pp.326-343.

Walsh, J. P., & Ungson, G. R., 1991. Organizational Memory. *Academy of Management Review.* 16(1), pp. 57-91.

Ward, M., 2001. A survey of engineers in their information world. *Journal of Librarianship and Information Sciences*, 33(4), pp.168-176.

Wasiak, J., Hicks, B., Newnes, L., Dong, A. & Burrow, L., 2010. Understanding engineering email: the development of a taxonomy for identifying and classifying engineering work. *Research in Engineering Design*, 21(1), pp.43-64.

Weber, R.P., 1990. Basic Content Analysis, 2nd ed., *Quantitative Applications in the Social Science Series,* 49, Newbury Park, CA; London: Sage Publications.

Weiser, M. & Morrison, J., 1998. Project memory: Information management for project teams. *Journal of Management Information Systems* 1998; 14(4), pp.149-166.

Wharton, C. and Jeffries, R., 1993. *Understanding the role of structure in information filtering in the context of group memories: Some application and user requirements.* CS Technical Report - CU-CS-686-93, University of Boulder Colorado, USA.
Available at: http://www.cs.colorado.edu/department/publications/reports/docs/CU-CS-686-93.pdf (accessed 3 July 2010).

Wild, P.J., Culley, S.J., McMahon, C.A., Darlington, M.J., & Liu, S., 2005. Starting to Audit Documents in the Engineering Domain. In P. Amaldi, S.P. Gill, B. Fields & W. Wong, eds. *In-Use, in-Situ: Extending field research methods,* London, 27-28 October.

Wild, P. J., Culley, S.J., McMahon, C.A., Darlington, M. J. & Liu, S., 2006. Towards a method for profiling engineering documentation. In D. Marjanovic, ed. In Proceedings of *The 9th International Design Conference DESIGN 2006,* Dubrovnik, Croatia, 15-18 May, pp.1309-1318.

Wild, P. J., McMahon, C. A. & Culley, S. J., 2007. Introduction to special issue on empirical approaches in design information and knowledge. *Journal of Design Research,* 6(3), pp. 289-294.

Wild, P.J., McMahon, C.A., Darlington, M., Shaofeng, L. & Culley, S.J., 2010. A diary study of information needs and document usage in the engineering domain. *Design Studies*, 31(1), pp.46-73.

Wilkinson, S., 1999. Focus group methodology: A review. *International Journal of Social Research Methodology,* 1(3), pp.181-203.

Wodehouse, A., Grierson, H., Ion, W.J., Juster, N., 2006. Student searching behaviour in a digital library. In: Proceedings of *The International Engineering and Product Design Education Conference '06*, 7-8 September, Salzburg, Austria.

Wodehouse, A., Breslin, C., Eris, O., Grierson, H., Ion, W., Jung, M., Leifer, L., Mabogunje, A., Sonalkar, N., 2007. A reflective approach to learning in a global design project. In: Proceedings of *The International Engineering and Product Design Education Conference '07*, Northumbria University, Newcastle, UK, 13-14, September.

Yin, R.K., 2003. *Case study research: Design and methods* (3rd ed.). Beverly Hills, CA: Sage Publishing.

Zavbi, R. & Tavcar, J., 2005. Preparing students for work in virtual product development teams. *Computers & Education*, 44(4), pp.357-376.

Zhao, Y., Tang, L.C.M., Darlington, M.J., Austin, S.A., Culley, S.J., 2008. *Information evaluation: empirical investigations in engineering organisations.* Loughborough University Institutional Repository. Available at: http://hdl.handle.net/2134/5053 (accessed 2 July 2010).