

Table of Contents

Abstract.....	iii
Acknowledgements.....	v
Table of Contents.....	vii
List of Figures.....	xv
List of Tables	xvii
1. Introduction.....	1
1.1. Background.....	1
1.2. Context of the Study	1
1.3. Problem Statement.....	4
1.3.1. Purpose Statement.....	8
1.3.2. Research Questions	8
1.3.3. The Problems in Detail.....	9
1.3.3.1. Problems 1 & 2 - Low levels of student engagement and motivation	9
1.3.3.2. Problem 3 –The concept of systems integration.....	10
1.3.3.3. Problem 4 – Indeterminacy of problems	11
1.3.4. Definition of Ill-Defined Domains.....	12
1.4. Stages of the Research	13
1.4.5. Details of the Stages.....	14
1.4.5.1. Stage 1: Conduct a literature review	14
1.4.5.2. Stage 2: Establish a research paradigm	14
1.4.5.3. Stage 3: Design and develop the educational intervention.....	14
1.4.5.4. Stage 4: Apply the educational intervention	14
1.4.5.5. Stage 5: Assessment of research data.....	15
1.4.5.6. Stage 6: Review of the outcomes of the research.....	15
1.5. The Structure of the Research Report.....	15
1.6. Ethical Considerations, Limitations and Delimitations	16

1.6.6. Ethical Procedures	16
1.6.7. Limitations	16
1.6.8. Delimitations	17
1.7. Significance and Benefits of this Research	17
2. Literature Review	19
2.1. Introduction	19
2.1.1. Outline of the Review	19
2.2. The Review Process	21
2.3. Theories of Learning	21
2.3.2. Behaviourist Models	22
2.3.3. Cognitive models	24
2.3.4. Constructivist models	25
2.4. Computer Technology and Engineering Education	29
2.4.5. Past Applications of Technology in Education	29
2.4.6. Computer Technology and Practitioners	34
2.4.7. Applications of Computer Technology to Engineering Education.....	37
2.4.7.1. Multimedia in engineering education	39
2.4.7.2. Simulation games in engineering education	41
2.4.7.3. Simulation in engineering education	43
2.4.7.4. Simulation applications - examples	44
2.5. Models of Instruction for Virtual Environments.....	55
2.5.8. Introduction	55
2.5.9. Educational taxonomies.....	56
2.5.10. Gagné Events of Instruction	57
2.5.11. Situated Learning.....	58
2.6. Factors Influencing Student Learning	64
2.6.12. Narrative	64
2.6.13. Motivation	69

2.6.14. Student Approaches to learning	73
2.7. Accommodating Learners.....	78
2.7.15. Learning Styles.....	78
2.7.16. Theories of Intellectual Development	81
2.7.16.1. Perry’s model of intellectual development.....	83
2.7.16.2. Intellectual Development Measurement.....	85
2.7.16.3. Perry’s positions	86
2.8. Ensuring No Duplication of Effort	88
2.9. Summary	89
2.9.17. Theories of Learning:	89
2.9.18. Computer-based technology applied to engineering education:	90
2.9.19. Pedagogical models and other factors	92
2.9.19.1. Learning Styles and Perry	95
2.9.19.2. Benefits.....	95
3. 3. The Research Methodology	97
3.1. Introduction.....	97
3.2. Selection of the Research Methodology	97
3.2.1. Research Methodology – Alternative Strategies.....	97
3.2.2. Appropriate Methodology - Selection.....	103
3.2.3. Design-Based Research – Steps to Implementation.....	108
3.2.4. Ontological and Epistemological Issues	109
3.3. Ensuring Trustworthiness of the Study.....	110
3.4. Data Collection Methods	113
3.4.4.1. Questionnaires	113
3.4.4.2. Interviews	114
3.4.4.3. Observation.....	115
3.4.4.4. Kolb’s Learning Styles Inventory	116
3.4.5. Reliability and Validity of the LSI.....	117

3.4.5.1. Moore's Learning Environment Preferences instrument	118
3.4.6. Reliability and Validity of the LEP	118
4. Intervention Design and Application	121
4.1. Introduction	121
4.2. The Intervention – Design & Development	123
4.2.1. Stage 1: Analysis.	123
4.2.1.1. Topic selection	123
4.2.1.2. Task selection.....	127
4.2.2. Stage 2: Design	132
4.2.3. Stage 3: Development.....	133
4.2.4. Stage 4: Implementation	133
4.2.5. Stage 5: Evaluation	135
4.3. Pilot Design	135
4.3.6. The Task – Ergonomics	136
4.3.7. The Tools – ErgoEASE®	138
4.3.8. Narrative	139
4.3.9. Evaluation	140
4.4. Intervention – Iteration One	141
4.4.10. The Tasks – Plant Layout, Modelling & Simulation.....	143
4.4.10.1. Plant layout	143
4.4.10.2. Production line modelling and simulation	144
4.4.11. Tools – Visio® and Arena®	145
4.4.12. Narrative	146
4.5. Iteration Two	148
4.5.13. Evaluation	150
4.6. Intervention - Iteration 3	150
4.6.14. The Task – Finite Capacity Scheduling & Lean Manufacturing.....	151
4.6.15. The Tools	153

4.6.16. Narrative.....	153
4.6.17. Evaluation.....	156
4.7. Intervention - Iteration 4	156
5. Data Collection & Results	159
5.1. Introduction.....	159
5.2. Data Collection Programme.....	160
5.3. Data Collection	161
5.3.1. Data - Pilot Design	161
5.3.1.1. Student Questionnaire Structure.....	161
5.3.1.2. Pilot Design – Results of Student Questionnaire, Part A	162
5.3.1.3. Pilot Design – Results of Student Questionnaire, Part B	164
5.3.1.4. Researcher Observations	166
5.3.1.5. Summary.....	168
5.3.2. Data – Design Iteration One.....	169
5.3.2.1. Student Group Interviews.....	169
5.3.2.2. Researcher Observations	170
5.3.2.3. Summary.....	171
5.3.3. Data – Design Iteration Two	172
5.3.3.1. Student Interviews	173
5.3.3.2. Student Interviews	174
5.3.3.3. Researcher Observations	177
5.3.3.4. Summary.....	178
5.3.4. Data - Design Iteration Three.....	179
5.3.4.1. Researcher Observations	179
5.3.4.2. Moore’s Learning Environment Preference Instrument.....	181
5.3.4.3. Summary.....	183
5.3.5. Design Iteration Four	184
5.3.5.1. Student Questionnaire, Part A	184

5.3.5.2. Student Questionnaire, Part B	185
5.3.5.3. Student Semi-Structured Interviews	187
5.3.5.4. Researcher Observation	197
5.3.5.5. Kolb's Learning Styles Index	198
5.3.5.6. Moore's Learning Environment Preference.....	200
6. Discussion, Conclusions & Recommendations.....	203
6.1. Introduction	203
6.2. Summary of the Study	203
6.2.1. Overview of the Problem.....	203
6.2.2. Purpose Statement & Research Questions.....	204
6.2.3. Review of the Methodology	205
6.3. Major Findings	208
6.3.4. Research Question 1	208
6.3.4.1. Levels of motivation	208
6.3.4.2. Levels of engagement	210
6.3.4.3. Conception of integration	210
6.3.4.4. Acceptance of indeterminacy.....	211
6.3.5. Research Question 2	212
6.3.6. Other Findings	214
6.3.6.1. Compatibility with student learning styles	214
6.3.6.2. Appropriate level of task indeterminacy	215
6.4. Conclusions	216
6.5. Implications for Teaching & Action	216
6.6. New Design Methodology	218
6.7. Recommendations for Future Research	220
6.8. Concluding Remarks	221
7. References	223

Appendix A : Team Detectors Scenario	253
Appendix B : Team Detectors Realia	255
Appendix C : Team Detectors Manuf. System Documents.....	257
Appendix D : Ethics Document	259
Appendix E : Data Collection Instruments	261
Appendix F : Peer Review of Research	263
Appendix G : Notes on Course Development & Structure.....	265

List of Figures

Figure 1-1: Issues in the Delivery of Manufacturing Systems Courses	8
Figure 2-1: Overlaps Between Multimedia, Games and Simulation Applications.....	38
Figure 2-2: Elements of Situated Learning (Adapted from Herrington, 1996)	61
Figure 3-2: Predictive Research & Design-based Research Compared	107
Figure 4-1: Intervention Web Site, Pilot Design	136
Figure 4-2: A Still Clip from the Video.....	138
Figure 4-3: A Screen Capture from the ErgoEASE® Program.....	139
Figure 4-4: INFOstation's Revised Web Site.....	141
Figure 4-5: Typical Solution to Simulation Task	147
Figure 4-6: Team Detectors Limited - Auckland Premises	148
Figure 4-7: Team Detectors Limited – Website, Home Page.....	150
Figure 4-8: 3D Model of Virtual Product, Ion Chamber Assy.	152
Figure 4-9: Finite Resource Scheduling Task.....	153
Figure 4-10: Team Detector's Reception Area	156
Figure 5-1: Response to Questionnaire, Part A, Pilot Design	164
Figure 5-4: Distribution of Perry Positions.....	183
Figure 5-5: Student Responses to Questionnaire, Part A.....	185
Figure 5-6: Student Responses to Questionnaire, Part B.....	187
Figure 6-1: The Virtual Enterprise Environment.....	219
Figure 6-2: Modular Intervention Design Process.....	219
Figure 6-3: Intervention Design Flow Chart.....	220

List of Tables

Table 2-1 Current Examples of Virtual Factory/Lab Research	49
Table 3-1: Establishing Trustworthiness	112
Table 4-1: Companies Consulted for Course Input	124
Table 4-2: ‘Ideal’ List of Manufacturing Systems Course Topics	125
Table 4-3: Virtual Enterprise Tasks.....	129
Table 4-4: Task Design Template/Checklist	131
Table 4-5: Virtual Enterprise, Record of Iterations	134
Table 5-1: Structure of Student Questionnaire	162
Table 5-2: Student Questionnaire, Part A.....	163
Table 5-3: Pilot Design, Questionnaire (Part A) - Merged Responses.....	163
Table 5-4: Student Questionnaire, Part B	164
Table 5-5: Pilot Design, Questionnaire (Part B) - Merged Responses	165
Table 5-6: Student Interview, General Structure, Iteration 2	174
Table 5-7: Numbers and Percentages of Kolb Learning Styles.....	180
Table 5-8: Perry Positions.....	182
Table 5-9: Student Questionnaire, Part A.....	184
Table 5-10: Iteration 4, Questionnaire (Part A)-Merged Response.....	184
Table 5-11: Student Questionnaire, part B	186
Table 5-12: Iteration 4, Questionnaire (Part B)-Merged Responses	186
Table 5-13: Student Interviews, General Structure	188
Table 5-14: Mean and standard deviation scores, Kolb primary variables	199
Table 5-15: Numbers and percentages of the four Kolb learning styles	199
Table 5-16: LEP Results, Iteration 4	200
Table 6-1: The Addition of the Current Research to Existing Intervention	218
Table 7-1: Structure & Assignments of the Pre-intervention Course.....	265
Table 7-2: Redesigned Structure of Post-Intervention Course	267

1. Introduction

1.1. Background

This first chapter introduces the research programme, describes the context within which the research problem arises, and provides a statement of the practical pedagogical problems that initiated this study. The purpose and expected outcomes of the research study are described and the significance of the study explained in the light of these outcomes.

The chapter ends with sections describing the structure of this research report, the procedures adopted to address any possible ethical concerns and a comment on the trustworthiness of the study.

1.2. Context of the Study

The education of prospective engineers in undergraduate degree engineering courses is carried out, in the main, by the delivery of engineering topic materials via lectures, tutorial sessions and practical laboratory experiments. The traditional lecture is usually complimented by the use of printed lecture notes and/or a textbook. Reinforcement of the material covered is generally attempted by presenting students with textbook problems in which the data required to solve the problem is presented unambiguously and in its entirety. There is ongoing debate about the effectiveness of this traditional didactic teaching approach and many practitioners have supplemented their lectures and tutorials with project-based and problem-based learning activities in an attempt to provide variety and alternative learning mechanisms for students (McCarthy et al., 2002, Bütün, 2005: 223-233, Gijbels et al., 2005: 27-61, Seidel and Godfrey, 2005, Tedford et al., 2006: 1-13).

A similar but alternative approach has been adopted by Larry Leifer at Stanford University who prefers the phrase ‘product-based learning’ to ‘project’ or

‘problem’ based learning because the word *product* focuses attention on students delivering something of value beyond that of an "academic exercise" (Leifer, 1995).

Leifer outlines the objectives of ‘product-based learning curricula as follows:

- Familiarise students with problems inherent in their future profession.
- Assure content and process knowledge relevant to these problems.
- Assure competence in applying this knowledge.
- Develop problem formulation and solving skills for these problems.
- Develop implementation (how to) skills.
- Develop the capacity to lead and facilitate collaborative problem solving.
- Develop the skills to manage emotional aspects of leadership.
- Develop and demonstrate proficiency in self-directed learning skills.

Undergraduate degree programmes in mechanical engineering contain a preponderance of well-structured, primarily quantitative topics based upon the physical sciences, e.g. mechanics, thermodynamics and engineering materials. In these courses students learn that there is generally a formal, correct procedure with which to approach a solution and, generally, only one, right answer to the questions and problems that they are set.

The debate about the best pedagogical approach for effective delivery of these well-structured, engineering domains continues and the literature indicates that no consensus is currently in sight (Cronje and Coll, 2008: 295-309, Jones, 2007: 397-406). This research study, however, will examine the delivery of a contrasting category of engineering domains in which there is considerably more disquiet about the traditional forms of delivery. These are the broad engineering areas of engineering management and engineering design which are relatively ill-structured, complex and primarily non-quantitative. In particular this research study will attend to a domain present in some form in most undergraduate degrees in engineering—manufacturing systems, or manufacturing management.

The problem with the procedural approach to problem solving described above is that it is not representative of the methodology required for real-life engineering problems. Here the data are often vague, contradictory and perhaps out-of-date and there are generally many ways to go about solving the problem and many possible answers. This

multifariousness demonstrating what Ferguson (1992) calls, “the incalculable complexity of engineering practice in the real-world”.

Undergraduate degree students need to be able, or at least begin to be able, to deal with ill-defined problems, make decisions about which data to utilise, be able to accept approximations, to simplify problems by neglecting inconsequential issues and to compromise. Jonassen (2000: 63-85) explains that some researchers have assumed for some time that the ability to solve problems of a well-structured nature would transfer positively to learning to solve ill-structured problems and he quotes Simon (1978: 271-295) as an example; “in general, the processes used to solve ill-structured problems are the same as those used to solve well structured problems”. However, Jonassen argues that more recent research in situated and everyday problem solving makes it clear that there is a distinction between the thinking required to solve well-structured problems and that required for ill-defined, ‘everyday’ ones. Dunkle, Schraw, and Bendixen (1995) also concluded that there was no relationship between performance in solving well defined problems and performance on ill-defined tasks.

An ill-defined domain is categorised by Lynch, Aleven, et al. (2006) as one in which there is a lack of a systematic way in which to determine if a proposed solution is optimal, and by King and Kitchener (1994) as one in which problems cannot be described with a high degree of certainty or completeness. The concept of ‘ill-defined’ is an important one for this study and a more detailed definition is given in Section 1.3.4.

For courses containing topics from ill-defined domains, the consensus in the literature on the suitability of the didactic pedagogical approach is much clearer than that for more well-defined domains—it is held to be unsatisfactory and the topics are not taught adequately in this manner. Commenting on university courses in manufacturing, Sanderson (1997) says that, “the type of analysis, modelling and decision-making required to integrate manufacturing into real-world applications are beyond the scope of traditional lecture and textbook materials”, whilst Dessouky (2000: 167-180) writes that, “traditional pedagogy in manufacturing [courses] is ill-equipped for the task”. Woolf et al. (1999) maintain that, “New tools that go beyond simple classroom lectures are desperately needed in [manufacturing] engineering education”.

Laurillard (2002: 268) makes the interesting point that traditional ‘describing’ pedagogy provides “a second-order experience of the world”. With no first-hand experience of the domain being studied to draw on students may well create inaccurate cognitive models of the concepts within it. An example of this ‘second-order’ effect is in evidence in the manufacturing systems course under consideration. Each year, in a factory planning and layout exercise, a number of otherwise generally competent students make basic errors such as placing the visitor reception area at the rear of the site and the despatch department in the middle of the building with no access to an outside wall or van dock.

In addition to the disquiet voiced by educational commentators, there are calls by industry for undergraduates to have more competence in dealing with realistic and real world engineering problems. Hargrove and Dahleh (2006: 10) suggest that the challenge for engineering educators is to develop more innovative methods for instruction and learning in order to replicate real-world problem solving.

Thus, it is clear from the literature, and from the researcher’s personal experience, that the traditional didactic method of engineering course delivery is an unsatisfactory vehicle for presenting courses in complex ill-defined engineering domains. In Section 1.3 the problems that arise are considered in more detail.

This research study will seek to address these issues and provide an additional “new tool” as called for by Woolf and will accept Hargrove’s and Dahleh’s challenge for more innovation to provide “replication of real world problem solving”.

To limit the size of the research project this study will focus on the complex, ill-defined domain of manufacturing systems although it is expected that the teaching intervention and design methodology created will be transferrable to other engineering domains with the same ill-defined characteristics.

1.3. Problem Statement

The current, typical delivery method for the complex, non-quantitative domain of manufacturing engineering is problematical in that it appears to often give rise to a number of unsatisfactory outcomes. These include: producing generally low levels of student engagement; low levels of student motivation; a failure to impress upon students the integrated nature, or inter-connectivity, of the topics covered; and a continuing reluctance on the part of students to accept the validity of *approximate* solutions to

problems. These issues appear to arise as a result of the indeterminate nature of many of the problems encountered in the design and operation of manufacturing systems and of the segmented fashion in which the topics are often presented. Many students in manufacturing courses are described by Woolf et al. (1999) as, “bored, uninterested and unmotivated, particularly when enrolled in their one required ‘show and tell’ type undergraduate course dealing with manufacturing processes”. Jackson (1994) points out that, “Not all students are well served by the serial, abstract presentation style ... that characterizes most engineering programs. Some students need a context in order to grasp topics”.

At the University of Auckland these issues lead to undesirable consequences such as poor results in course tests and end-of-course examinations when compared to other structured, physical-science based subjects. Levels of student satisfaction with the course as reported in the School of Engineering feedback surveys was also low. Seidel and Sitha (1999) report that, “Students thought the topic area was “generally boring, unscientific and not very relevant”. Students also characterised the subject as ‘unscientific’.

In discussing the delivery of a related ill-defined course in engineering ethics, Bowden (2006), cited by Skinner (2007: 133-144) explains that engineers and their training are convergent – that is they employ analytical approaches that seek solutions. It is a training, he says, that is likely to find as unacceptable, a body of theory that does not provide answers or at best provides conflicting answers. Students may reject the course due, as far as they are concerned, to the unsatisfactory and incomplete nature of the underlying theory.

In summary, students attending courses in manufacturing topics often demonstrate:

- A lack of motivation.
- Low engagement with the course.
- Little, or no, awareness of the integrated nature of the manufacturing topics presented.
- Low tolerance towards the indeterminate nature of many problems.

In this context, motivation can be defined as: a desire on the part of the student to act; an incentive to stimulate learning; or, “the process whereby goal directed behaviour is

instigated and sustained” (Schunk et al., 2008). Engagement is defined as the presence of a level of emotional involvement, interest and commitment.

These four problems in the presentation of manufacturing engineering courses are examined in more detail in Section 1.3.3.

In a broader context, educational research has long been criticised for its weak link with practice (Akker, 2006: 1-8, Reeves, 2006: 86-109). Reeves (2000) believes that a good deal of educational research, including that taking place in the area of cyberspace and multimedia, has been dominated by an epistemology that treats learning theory apart from, and above, actual teaching practice. It is expected that this research study will be a contribution to the practical application of learning theory to the field of computer-based multimedia in engineering education. It is expected also that the research will go some way to providing a sound pedagogical basis, and an example of good practice, for educators involved in teaching complex non-quantitative issues to undergraduates in engineering degree programmes. At the same time, it will provide an effective, working educational intervention which will be made available to other practitioners in engineering education.

In a paper on the practice of educational research in university engineering departments Radcliffe (2003: 1-21) commented that, “The practice of teaching and learning in engineering schools has been notable for the almost complete absence of any underlying pedagogical model or theoretical framework. ...It is paradoxical that a teaching community whose courses hinge on theories and models does not see the need, collectively, to develop and discuss theories about the activity central to their role as scholars”. Laurillard (2001) also bemoans the fact that the transmission model of lecture, book and marked assignment is still the dominant one in universities.

Radcliffe also notes the observations of Wankat et al. (2002: 217-237) that “engineering professors... have always experimented with innovative instructional methods, but traditionally little was done to link the innovations to learning theories or to evaluate them beyond anecdotal reports of student satisfaction”, whilst Felder (2000: 208-215) says that “most engineering classes still consist of professors talking and writing on the board and students sitting and listening (or not listening)”.

A review of the literature in the fields of engineering education and the educational uses of multimedia simulation revealed no reports of a teaching intervention providing comprehensive answers to these issues. What appears to be required to overcome the problematic course outcomes discussed earlier, and to improve the connection between pedagogical theory and practice, is to provide an innovative learning experience based upon a valid pedagogical theoretical framework. An experience that, rather than containing a seemingly loosely connected collection of topics, examples and problems will be designed, from the beginning, to present the material and problem assignments in a logical and connected fashion. It is envisaged that this learning intervention, developed and validated by systematic analysis, will consist of a computer-based virtual manufacturing organisation, with the scenario delivered with the use of multimedia and web-based technologies. The organisation will provide students with “a clear orientation and sense of purpose”, as suggested by Sims (2000: 45-57), when moving within its structure.

The use of immersive teaching techniques in conjunction with multimedia tools has the potential to generate conditions for learning which will motivate and excite undergraduate students. A consistent, immersive scenario should be able to engage and encourage students to ‘care’ about the problems they are presented with and to motivate them to produce thoughtful and valid solutions.

The following figure, Figure 1-1, shows diagrammatically the issues and problems discussed in the problem statement.

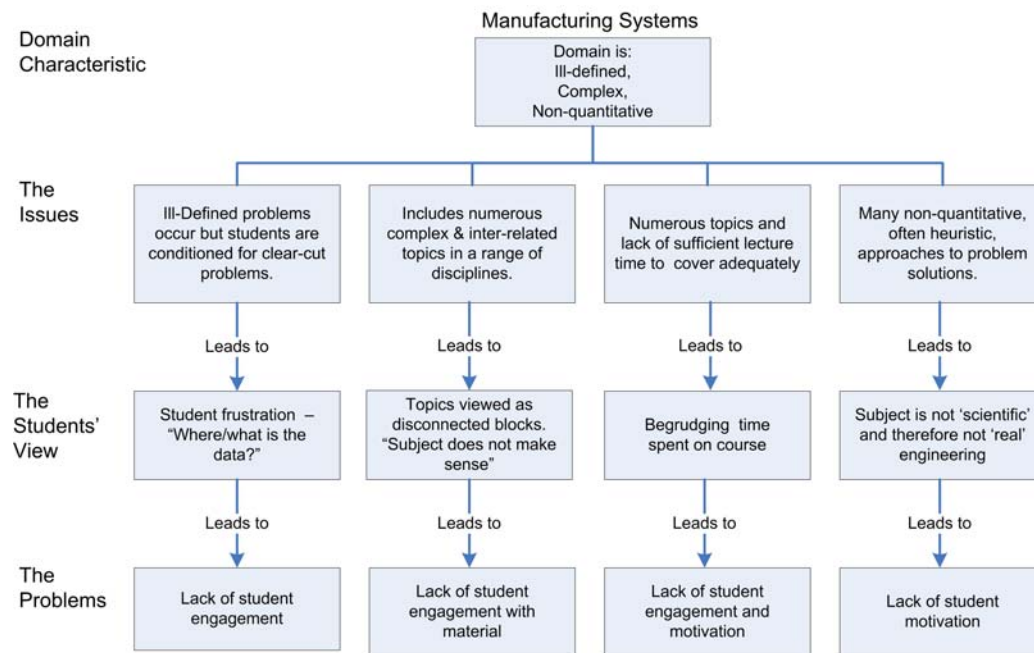


Figure 1-1: Issues in the Delivery of Manufacturing Systems Courses

1.3.1. Purpose Statement

The purpose of this study is to design, build and evaluate a novel and effective computer-based, multimedia, immersive teaching intervention, based upon a valid and appropriate pedagogical framework, to inform and improve courses in complex, ill-defined engineering domains. Specifically, for this research study, the domain of manufacturing systems.

Further, to establish a design methodology for the design and delivery of this category of courses and to validate the intervention and the methodology by its implementation in practice and by the analysis of user feedback.

1.3.2. Research Questions

The problem statement, in Section 1.3, concerning the *effective* utilisation of computer technology to teaching and of the application of a suitable pedagogical theory to underpin its use (in particular for engineering domains such as manufacturing systems) leads to the following research questions:

1. How can the current delivery of complex, ill-defined and non-quantitative topics in courses such as manufacturing systems be modified to improve student (a) motivation, (b) engagement and (c)

capability to perceive them as coherent and scientific bodies of knowledge?

2. What specific educational theories and pedagogical strategies would effectively form the framework for this improvement?

1.3.3. The Problems in Detail

The following section expands on the problems outlined earlier in the problem statement (Section 1.3) to provide a more comprehensive view of the issues.

1.3.3.1. Problems 1 & 2 - Low levels of student engagement and motivation

Engineering students studying some subjects not specifically dealing with the physical sciences often seem to feel that the material in the courses have nothing to do with ‘real engineering’. For instance, the University of Auckland, Year Three course ‘Engineering Management’ has often received feedback from students which indicates that they do not see the relevance of the course. A common remark is “*I came to study to be an engineer, not a manager*”. Some students maintain this attitude throughout the course despite many examples being given by staff of the importance of engineering management skills to graduates. Despite, also, the students’ attention often being drawn to the examples of recent graduates who have had to grapple with management roles soon after starting work as professional engineers. Similar comments indicating low levels of engagement are received about the management focussed topics in the manufacturing systems course.

Commenting on this issue of student involvement and commitment, Peter Goodyear (2000: 1-18) says that, “they don’t make as much use as we (their teachers) would like of the university library; they are too busy and it’s not on the critical path for any of the significant problems they have to solve each day ...supplementing their income and meeting the next coursework deadline take precedence over ‘reading around the subject’...”. He goes on to say “...the same kind of arguments apply to busy managers, knowledge workers and other creative people for whom very focused ‘just-in-time learning’ is all their stressed schedule can afford”.

Henkel (2000), as quoted by Bird, et al. (2007: 19-35), points out that there has been a shift in student expectations of university study, from being an educational experience to being a ‘credentialing’ one and she points to the diminishing interest in the

humanities as evidence of this view of education as a commodity, sought simply to gain employment. This is an attitude, which if common amongst engineering students, could be a contributor to a reduction in a commitment to, and involvement in, their chosen subjects for study. This would be particularly so if the student felt that the subject was not ‘real engineering’.

A further issue which may colour students’ attitudes to the manufacturing course is the fact that discussion of manufacturing systems, their purpose and personnel, can tend occasionally to move into ethical, societal and philosophical fields with which many engineering students seem uncomfortable.

To sum up, many students do not actively engage with, or feel enthusiastic about their participation in, what they feel are the non-core engineering topics (finance, management, communications, etc.) such as those included in professional development and engineering management and manufacturing courses. They feel that the material has no relevance to their future careers. Conversations with students, and observation of their coursework submissions, indicate that for many students much of the material covered appears as a disconnected sequence of topics and ‘unscientific’ methods.

1.3.3.2. Problem 3 –The concept of systems integration

Systems integration is the key to the operation of successful and profitable manufacturing organisations. An efficient manufacturing environment integrates a wide range of physical resources from stand-alone and continuous-flow machines through to raw materials, labour and material handling equipment. Less visible and tangible activities such as management planning, quality systems, and data collection and analysis also have to be seamlessly fitted into the operation. In manufacturing industries the processes of product design, systems/project control, and the management of manufacturing operations and equipment are interactive, dynamic and interrelated.

Topics in well-defined domains such as mechanics, thermodynamics, or control systems, tend to lend themselves well to the demonstration of their founding principles by direct observation or by experimentation in the laboratory. The topic of ‘systems integration’ for example, a characteristic of an efficient manufacturing system, is, by contrast, difficult to demonstrate, explore or manipulate in conventional lecture or laboratory sessions.

In their efforts to deal with this issue, many university engineering departments have adopted an industry project-based learning approach, or have utilised hands-on design and build projects, as described by Jensen, Wood et al. (2000) and Seidel and Tedford (2001: 415-416). The aim of these initiatives is to allow students to get first-hand experience of actual manufacturing systems and processes whilst at university. These programmes have had encouraging results at the University of Auckland with positive student feedback and significant gains in conceptual learning as described by Seidel and Godfrey (2005). Dym, Agogino et al. (2005: 103-120) also report that project-based learning initiatives at several American universities have increased student retention, satisfaction and learning in engineering courses. This project-based approach, whilst useful as far as it goes, does not generally solve all of the problems associated with providing the best possible learning experiences for students. Although students may discuss their project with the managers in the host company and obtain first-hand information about the company's organisational structure, culture, etc., they are generally not exposed to, and do not have time to explore, the full range of activities within the organisation. As explained by McCarthy (2004) and Dessouky et al. (2000: 167-180) the complexities and integrated operations of a typical manufacturing company are, generally speaking, not fully experienced or understood. Netherwood (1996) developed a computer based tutorial-simulation to support undergraduate manufacturing studies prompted by his observation that, "Undergraduate students do not have any background or conception of the issues involved in Manufacturing" and, in the same publication, bemoans the fact that, "Conventional teaching approaches tend ... to treat the subject as a series of distinct topics", an approach not conducive to recognising interrelationships and sound planning strategies.

The issue is: how can students be given the capability to grasp the whole picture? How can a teaching methodology be developed that gives students an understanding of how each sub-process or system combines with others to form a fully functional manufacturing organisation?

1.3.3.3. Problem 4 – Indeterminacy of problems

In traditional modes of teaching the design and management of manufacturing systems, the rules and heuristic techniques used in such systems are taught without including all the problems that these practices encounter in their practical implementation. These

problems can arise from factors such as: missing, or poor, inter-personal communications; poorly-trained staff; incorrect data; software errors, etc. As Nicholson (2000) points out in discussing operations management education, this area of study has lost its link back to working in the workplace, and he describes students carrying out industry-based projects as “outsiders with no awareness of the internal work of the organisation” and “The reality was that students of all ages had no idea how to analyse and perceive a working business operation. The educational and research material was enabling them to comment but not to manage or participate”.

Skinner et al. (2007: 133-144), in discussing another ill-defined domain with problems containing indeterminacy (engineering ethics), says that, “students still express a lingering fear about assessment tasks that do not have a single, unambiguous, correct answer”.

The observations by Skinner and Nicholson have an eerie ring of similarity with comments that are received at the University of Auckland from manufacturing systems students in their written reports of field trips to local engineering companies. Despite the material they have digested on the course they have difficulty aligning the theory with observed on-site practice. Clearly the real-life management of manufacturing systems is not the same as ‘Manufacturing Systems Management’.

A further issue is that the design and operation of manufacturing systems is often undertaken with tools of an heuristic nature which produce solutions which are workable, but are not usually amenable to being proved to be optimal. Students often have difficulty accepting that many problems they may encounter have no single, right answer, or may not have a feasible answer at all. As a recently graduated engineer reported in the course of an interview (2006: 139-151), “It is kind of a sore spot with me that educational institutions teach that when you do your work there is a right answer and a wrong answer. And in the real world it is never that way, there are many ways to do things and it is not a matter of getting a right answer it’s a matter of working for the best solution for your particular situation”.

1.3.4. Definition of Ill-Defined Domains

Complex, primarily non-quantitative domains such as the design and operation of manufacturing systems, engineering management and engineering design are considered

to be ill-defined meeting as they do McCarthy and Minsky's (1995: 47-49) definition of an ill-structured domain as one in which there is a lack of a systematic way in which to determine if a proposed solution is optimal, quoted by Lynch, Aleven, et al. (2006). King and Kitchener (1994) explain that a problem can be considered ill-structured if it cannot be described with a high degree of certainty or completeness and where, "experts may disagree about the best solution, even when the problem may be considered solved". Ashley et al. (2004) (quoted in the same publication) offer a more detailed, but complimentary definition, and describe them as domains which have the following characteristics: the problems lack a definitive answer; the answers are heavily dependent upon the way the problem is conceived; and problem solving requires both retrieving relevant concepts and mapping them to the task at hand. Spiro (1995) in a definition which, because of its emphasis on knowledge transfer from case to case, is particularly suited to ill-defined domains in engineering, holds that:

"An ill-structured knowledge domain is one in which each case or example of knowledge application typically involves the simultaneous interactive involvement of multiple, wide-application, conceptual structures (multiple schemas, perspectives, organisational principles, and so on), each of which is individually complex, and the pattern of conceptual incidence and interaction varies substantially across cases nominally of the same type".

That is, importantly, the domain involves across-case irregularity. For example, modelling and simulating two seemingly identical manufacturing processes in similar environments, may, despite their apparent similarities, require two substantially different approaches as a result of complex interactions among many indeterminate systems parameters. One size does not fit all. This issue of ill-structuredness in the domain of manufacturing systems is an obstacle to mastering the interconnectedness of the field and the ability to apply knowledge to new problems.

1.4. Stages of the Research

In view of the content of the research questions the main goal of this study will be to design and implement a computer-based, multimedia teaching intervention based upon recognised learning theories and presented within a valid and recognised pedagogical framework.

This research programme will be carried out in six stages. The stages are;

1. Conduct a literature review.
2. Establish a relevant research paradigm.
3. Design and develop the educational intervention.
4. Apply the educational intervention.
5. Assess the research data.
6. Review the outcomes of the research.

1.4.5. Details of the Stages

1.4.5.1. Stage 1: Conduct a literature review

The literature review (Chapter 2) will examine recent research in the application of computer-aided learning and multimedia in engineering education with particular emphasis on the use of multimedia and simulation to provide immersive characteristics to the intervention. The major educational philosophies and learning theories will be reviewed with a view to identifying relevant paradigms for the proposed educational intervention. The review will also examine such relevant associated areas as: narrative as an aid to learning; motivation; student approaches to learning; and the literature concerning learning styles and students' intellectual development. The design of the proposed intervention will be informed by the findings of the literature review.

1.4.5.2. Stage 2: Establish a research paradigm

In Stage Two a suitable research paradigm will be adopted for application to the intervention. The selection of an appropriate paradigm will be guided by the particular circumstances of this research and the teaching environment within which the proposed intervention will be applied.

1.4.5.3. Stage 3: Design and develop the educational intervention

In this stage the virtual enterprise concept will be designed according to the instructional design and pedagogical principles established as relevant to the intervention in Stages 1 and 2. Following the application of the intervention any revisions required to the design, as indicated by experience, and student feedback from Stage Four, will be implemented.

1.4.5.4. Stage 4: Apply the educational intervention

The educational intervention will be applied to the University of Auckland 'Manufacturing Systems' course. Feedback from students in the form of questionnaires,

group and semi-structured interviews and researcher observation will be collected. Any changes required to the design will be implemented as the intervention is refined in an iterative manner and re-applied. During this stage also, data concerning students' learning styles and level of intellectual development will be collected to assist in meeting the objective of congruence between student characteristics and the pedagogy of the intervention.

1.4.5.5. Stage 5: Assessment of research data

This stage will provide a record of the data collected during the application of the iterations carried out in Stage 4 with an assessment and analysis of the results.

1.4.5.6. Stage 6: Review of the outcomes of the research

Stage 6 will consist of a review of the research, conclusions drawn from the assessment data, a discussion of the results and recommendations for further research.

1.5. The Structure of the Research Report

This chapter, Chapter One, provides a description of the background to the research and outlines the research objectives. It describes the planned stages of the research programme, the expected benefits of the research, and some limitations of the research study.

Chapter Two contains a review of the literature on a number of topics of interest in this research context including current applications of computing and multimedia to engineering education, pedagogical theories, student motivation and approaches to learning, the use of narrative, and the issues of variation between students of learning styles and levels of intellectual development. The chapter concludes with a discussion about, and selection of, of a suitable pedagogical framework for the proposed intervention.

Chapter Three describes the research methodology to be adopted in designing and applying the intervention and collecting data. Chapter Four is concerned with a description of the design and development process for the virtual enterprise teaching intervention and of the implementation and application of the intervention to several successive manufacturing systems courses at the University of Auckland.

Chapter Five presents the data which was collected during applications of the teaching intervention, an analysis of the results and discussion of the research questions. The

thesis concludes with Chapter Six which is concerned with a summary of the research findings and suggestions for further research in the area of multimedia and virtual enterprise concepts applied to the teaching of ill-structured engineering domains.

1.6. Ethical Considerations, Limitations and Delimitations

1.6.6. Ethical Procedures

All necessary measures were taken during this programme of research to ensure that the rights of students were observed. In particular, contributors were assured that participation was entirely voluntary and that participation or non-participation would not affect their grades or relationships with teaching staff in any way. Students were also informed that any publications arising out of this study would not identify any individuals and that they could withdraw themselves and any associated data, from the study at any time.

The appropriate research approvals for the collection of data from surveys and student interviews were sought from, and granted by, the University of Auckland Human Participants Ethics Committee. Details of the survey and interview instruments, participant information, consent documents, and approval documents from the committee are included in Appendix D.

For the last iteration the ethical safeguards were added to by utilising a third-party to keep the survey documents sealed and locked away until after the final student grades for the course were published.

1.6.7. Limitations

The following limitations to the generalisation of the results of the study were recognised:

- Some of the data was self-reported and therefore may reflect bias on the part of the participants.
- The results and the conclusions drawn from them were based upon the data from the respondents.

1.6.8. Delimitations

A delimitation of the present study is that the population studied is that of academically very able third-year students in a four-year undergraduate degree programme in mechanical engineering.

1.7. Significance and Benefits of this Research

The significance of this research study lies in the novel solution proposed to the research questions posed in Section 1.3.2. Whilst the literature reveals that a number of computer-based, multimedia teaching interventions in engineering education have been proposed and implemented none embodies the scope of this particular solution to the problems of delivering complex, ill-defined and non-quantitative domain topics to engineering students.

It is intended that the proposed intervention will be created with a unique, comprehensive and coherent scenario within which a computer-based virtual organisation will exist. This organisation will be used as an authentic environment within which to deliver, explore and experiment with, topics covering the full spectrum of a manufacturing organisation's activities; from initial plant design through to production and sales. Also significant is the use, in this context, of a sympathetic pedagogical framework within which the intervention will be designed and a design-based research methodology for its creation, implementation, revision and assessment.

It is expected that this research study will play an important role in understanding more about how techniques using computer-based multimedia tools, the Internet and the simulation of authentic contexts can assist in the effective delivery of content for ill-defined domains. This study will add to the research literature on authentic learning environments which Herrington (2006: 3164-3173) says is sparse in higher education. By providing an 'almost 'ready-to-go' example of authentic learning it might help to encourage practitioners to adopt it and avoid having to create it from scratch. A task that Herrington says is a complex and engaging one and, as a result of time pressures, promotes the tendency for lecturers to put their course on the web via intranets using systems such as Blackboard [or CECIL] and putting the focus on the delivery of information rather than learning.

The benefits of this study to colleagues in engineering education will be a detailed exemplar for their consideration for the delivery of ill-defined domains such as engineering and manufacturing management & engineering design. The intervention and the new methodology proposal will be available almost 'ready-to-go' saving time in development and preparation of teaching materials. The Virtual Enterprise is flexible and adaptable. They may adopt, adapt or improve it for their own teaching purposes.

By increasing levels of motivation and engagement and providing a better appreciation of the complexities of manufacturing systems and their problems this research study will also benefit future engineering students. This development will therefore, in the wider context benefit future employers and the community at large.

In a narrower and more specific context the outcome of the research study is expected to eliminate, or ease, the ongoing pedagogical issues that have been experienced at the University of Auckland in the delivery of engineering courses in ill-defined domains.

2. Literature Review

2.1. Introduction

This chapter describes the literature review that was carried out in a number of fields considered relevant to the scope of this current work. The review was performed in order to prepare for this research programme and to assist with forming answers to the research questions posed. The review was expected to assist in developing a practical design for the proposed teaching intervention and to assist in selecting a suitable pedagogical framework within which it could be applied. The review of literature also noted any other factors that may influence students' learning and their interaction with the intervention.

A review which was broad in scope was required as a consequence of the varied nature of the disciplines to be investigated to assist in the research effort and in the discovery of satisfactory solutions to the research questions. These disciplines included the social sciences, such as human psychology and education, and the applied sciences, such as computing and engineering. This review sought to examine the evidence that learning can be enhanced with the sympathetic use of computer technologies when used in conjunction with a sound pedagogical foundation. In particular, in the case of this research programme, by the implementation of a teaching intervention in the form of an immersive and comprehensive simulation of a manufacturing enterprise.

The important issue of the selection of an appropriate research methodology for the design, implementation and evaluation of the intervention, which is the focus of this work, is allocated a separate chapter (Chapter 3).

2.1.1. Outline of the Review

The first section of the review examined the pedagogical literature which describes and debates the numerous theories of how students learn. The three major theories of

behaviourism, cognitivism and constructivism were examined with a view to determining their relevance for application in this research study.

The next section describes the investigation that was made into the use of computer technology in education. It begins with a review of the, often disappointing, use of technology and was carried out in order to draw lessons from earlier mistakes on the grounds that, “Those who cannot remember the past are condemned to repeat it” (George Santayana, 1863–1952). Next examined was the related issue of the influence of educational practitioners themselves on the success, or otherwise, of technology-based initiatives in education.

Then, current examples of the educational use of computers as described in the literature were reviewed. Emphasis was placed on those utilising multi- and mixed-media teaching materials in undergraduate manufacturing engineering, engineering management and operations management courses. This examination was carried out in order to determine what work had been done over the past decade in this area and to discover, also, what gaps, if any, there were in the literature on the issue.

The next section describes the investigation into the literature on models of instruction in order to develop a suitable pedagogical framework for the proposed teaching intervention. Only those models which were thought relevant to an intervention utilising multimedia and computer technology were reviewed.

The literature on influences on student learning was examined next. This examination was carried out to identify factors which should be addressed in the design of the intervention to assist with answers to the research questions. Three factors were thought to be influential in improving the delivery of ill-defined courses — student motivation, student approaches to study and learning, and student engagement. Thus the review surveyed the literature concerning motivational theory, student approaches to learning (deep and surface) and narration and story.

It is important that the proposed teaching intervention is designed to be of benefit to as many students as possible and thus the penultimate section of the literature review examines ways in which this design feature can be assured. The evaluation of student learning styles as a way of matching the pedagogical design of the intervention with student preferences was examined and the literature concerning their validity and

reliability was noted, as were the criticisms of the concept of an individual preferred learning style. The Perry scheme of intellectual development was reviewed and its application in the form of Moore's Learning Environment Preferences instrument was examined. This instrument was seen as a way to assist in matching the level of indeterminacy of any ill-defined assignments in the intervention with students' current levels of intellectual development as measured on the Perry scale.

The chapter concludes with a summary and discussion of the material reviewed. It outlines how the information gathered will form the basis upon which the teaching intervention will be designed and constructed, with some confidence that it is soundly theoretically based, and that it incorporates what current research by others indicates is valid and appropriate practice.

2.2. The Review Process

An extensive search of the literature in the disciplines cited was carried out utilising the resources of the University of Auckland library and its Interloan facilities. Also used was the library's extensive access to repositories of e-books, online databases and paper and electronic copies of professional journals. These information sources were supplemented by Internet searches of other researcher's websites and conference proceedings. Secondary sources of relevant research and data, found from the references in these primary sources, have also been investigated

The research and publications covered are analysed and interpreted from the point of view of their application to practical undergraduate education with particular emphasis to the fields of complex, ill-defined domains such as manufacturing systems which require engineers to solve ill-structured problems in their design and operation.

2.3. Theories of Learning

Professor Tony Grasha of the University of Cincinnati, as a visiting lecturer at Ohio State University some years ago, entitled his talk, "How Can I Teach You If I Don't Know How You Learn?", quoted on web site ((a), 2006). Thus, in order to better approach the design of the proposed teaching intervention this section will explore briefly three of the major theories of how learning occurs. The three learning philosophies of most prominence in the literature, and most widely utilised, are

behaviourism, cognitivism and constructivism (Hergenhahn and Olson, 2005, Mergel, 1998). Each of these views of how humans come by 'knowledge' has implications, and offer competing alternative models, for the design of the intervention.

2.3.2. Behaviourist Models

For behaviourists, learning is the modification of an organism's behaviour brought about by experience, and behaviour is explained by means of the relationship between an external stimulus upon an organism and the subsequent response of the organism to that stimulus (Good and Brophy, 1990). No significance is placed upon any unobservable internal operations within the mind of the subject. Behaviour is determined solely by the organism's environment and its response to it. An important tenet of behaviourism is that a change in behaviour must be brought about by an *external* stimulus. Therefore, for example, a student will require someone, in addition to themselves, to plan and control what is learned and when. Students move from lower to higher level skills in a step-by-step manner (Roblyer, 2006).

Many computer-based multimedia teaching materials reflect the laws of 'effect' and of 'exercise' proposed by the behaviourist E. L. Thorndike. The law of effect states that, "responses to a stimulus that are followed by satisfaction are strengthened and that, conversely, responses that are followed by discomfort are generally, but not always, weakened" (Thorndike, 1932). Many educational multimedia programs follow this law by providing timely feedback and offering a reward for successful accomplishment of a task, e.g. a 'well done' message on the screen or permission to move on to the next level task. The later 'revised' law of exercise, which stated that behaviour may be more strongly established through frequent connections of stimulus and response ('practice makes perfect'), is followed by multimedia designers by providing the student with a number of exercises on the same theme or topic, e.g. 'Solve the following ten quadratic equations'.

One obvious criticism of the law of effect is that it seems to suggest that the effect precedes the cause. It appears to be a circular argument. Anticipating this objection Thorndike suggested that there was some form of feedback, from the behaviour to the stimulus producing the behaviour, which, at the least, strengthened the response to the stimulus. That it was a neurophysiologic reaction which strengthened neural bonds in

the brain and that the organism concerned was unaware of this action (Thorndike, 1912).

Interestingly, Thorndike's early speculations (1912) regarding technology and teaching are eerily prophetic of the emergence of computer-based 'click-through' teaching materials, "If, by a miracle of mechanical ingenuity, a book could be so arranged that only to him who had done what was directed on page one would page two become visible and so on, much that now requires personal instruction could be managed by print", quoted by Zimmerman and Schunk, (2002).

Applying behaviourist principles to the design of computer based, or computer assisted, instructional multimedia involves splitting the prime learning objective, or task, into smaller units which, when mastered, will lead to a learned behaviour which can be measured or assessed for satisfactory completion. Multimedia materials that will build these behaviours are then designed and produced.

Current examples of this form of behaviourist modelled software, for general educational use, are 'Fresh Baked Fractions' by Pearson Education Inc. and the 'Place Value Game' by Jefferson Labs.

Some behaviourist models of drill and practice educational software are less rigidly structured, tutorial-style, programs in which the student can follow non-linear branching paths through the material and, to some extent, choose the learning material being presented. An example of this form of software is Broderbund's 'Welcome to Physics'.

In the fields of engineering education and engineering management this drill and practice approach is not common although some examples exist. The 'Book of Management Games' by Epstein (1996) and the computer-based, spatial awareness exercises for engineering design students developed by the current author are typical examples.

A 'Bicycle Dissection Exercise' for mechanical engineering students at Stanford University (Regan and Sheppard, 1996: 123-130) contains one module that also adopts this pedagogical model. In this module students are asked to solve a puzzle to test their knowledge of the names of bicycle components and are provided with feedback about their score and their number of successful and unsuccessful attempts. Rossiter and Rossiter (2006) utilised drill and practice as a learning strategy to develop engineering

mathematics skills in one section of a multimedia learning project to teach the design and analysis of electrical circuits. The multimedia component of the drills was expected to provide increased motivation for students to engage with the materials. They report that this method had some success in increasing both the amount of formative feedback given to students and their assessment scores.

It appears from an examination of the literature that drill and practice strategies have their place when what is required is the memorising of information or procedures, although, in a discussion on the application of constructivism to engineering education (see Section 2.3.4), Fowler, McGill, et al. (2002) dispute this. They argue that, “effective learning cannot be achieved by behaviourist-based drill and rote learning”. A stance that seems somewhat extreme and at odds with much of the evidence in the training field (Vilamil-Casanova and Molina, 1996).

Although some behaviourist purists continue to believe that learning is demonstrated by observed performance only, most behaviourists today recognise that cognitive information processing must have a part in any theory and that learning is a *capacity* for cognitively driven performance rather than the performance itself.

2.3.3. Cognitive models

A movement away from behaviourism in the 1960's was driven by the concerns of many educational theorists over the insistence by behaviourists on strict objectivity and reliance on only externally observable changes in behaviour as indicators that learning had taken place. This stance meant that many of the everyday phenomena that individuals experience were left out of consideration in the behaviourists' concept of learning. For example, mental experiences such as insight, images 'in the mind's eye', intuition and feelings were ignored. It was noted that Staddon has proposed an alternative to this radical approach — theoretical behaviourism, which accepts the use of unobservable internal mechanisms in understanding the results of experiments in behaviour (Keijzer, 2005: 123-143).

The behaviourists' insistence that there was a secure and unchanging link between stimulus, response and reward was a problem for many researchers who believed that the connection between stimulus and response was nothing like so straightforward. For example, children do not imitate all behaviour that has been reinforced (Bandura and

Walters, 1963). Furthermore, they may model new behaviour, without reinforcement, days or weeks after their initial observation. These anomalies led Bandura and Walters (1963) to theorise, that an individual could model behaviour by observing the behaviour of another person. This work led to *Bandura's Social Cognitive Theory* (Bandura, 1989: 1-60) which is examined in more detail in Section 2.3.4.

Cognitivism is defined by the Oxford English Dictionary as 'the mental acquisition of knowledge through thought, experience, and the senses' and by Bruning, Schraw and Ronning (1995), as:

“... a theoretical perspective that focuses on the realms of human perception, thought, and memory. It portrays learners as active processors of information, a metaphor borrowed from the computer world, and assigns critical roles to the knowledge and perspective students bring to their learning. What learners do to enrich information, in the view of cognitive psychology, determines the level of understanding they ultimately achieve”.

Cognitive psychology then, examines the mental processes that are occasioned by stimuli and, which cognitive theory suggests, affect the type and timing of the responses to these stimuli or indeed if any response is to be made at all. Thus, cognitive theory is concerned with memory, mental imagery and, for some proponents, with introspection and self-commenting (Kosslyn, 1980).

Mishkin and Appenzellert (1987: 80-89) believe that most kinds of learning actually make use of both behaviourist and cognitive techniques.

2.3.4. Constructivist models

In the 1970's a number of researchers began to oppose the focus on cognitive or information processing that was current and began to argue for attention to be paid to the actual content of student thinking. It was argued that the student was a 'constructor' of knowledge not simply one who responded only to external stimuli or acted as an information processor.

The constructivist view is that learners construct knowledge in an active way as they attempt to make sense of their experiences. This is done by constructing mental models, built upon existing knowledge, which are adjusted and changed to fit new experiences

and ideas. Thus, the mind maintains an internal model of the external world and one's perception of this seemingly real outside world, and one's learning, arises from how this internal model is interpreted, re-interpreted and modified. Learning is an active process in which the learner constructs new ideas or concepts based upon their current and/or past knowledge (Bruner, 1966: 176). A student will learn most about a particular subject when he or she learns how to, "[obtain] knowledge for oneself for use of one's own mind" (Bruner, 1961: 21-32), quoted in Driscoll (2005).

Bransford et al. (2000: 319), point out that, in the past few years, "...the view of how effective learning proceeds has shifted from the benefits of diligent drill and practice to focus on students' understanding and application of knowledge". Today most educational multimedia developments utilise cognitive and constructivist learning theories in their design.

This substantial theoretical shift over the last few decades from behavioural to cognitive to constructivist learning perspectives among educators is noted by Herrington and Standen (2000). They describe the, not inconsiderable task, at the University of Wollongong, to re-design a business studies multimedia program, from one cast in the behaviourist mode to one underpinned with a constructivist philosophy.

Piaget (2001), whose work foreshadowed constructivism, described four stages of human cognitive development. The sensorimotor stage (from birth to about two years of age) where physical and motor activity such as crawling and walking facilitate the growth of knowledge of the environment. Except towards the end of this stage, there is no use of, or understanding of symbols. Following this stage comes the pre-operational stage, from about two years of age to about seven. Children at this level of development are able to retain mental images of objects when the objects are not present, and remember events in their life. The end of this stage of development is signalled by the ability to conserve numbers so that the child knows, for example, that splitting a pile of blocks into several smaller piles does not reduce their quantity. When a child's egocentric thinking declines and they can look and interact with their environment from more than one perspective, and demonstrate logically integrated thought, they have reached Piaget's third stage, the concrete operational (ages seven to eleven). At, or about the age of eleven, the child reaches the formal operational stage of development.

Children confronted by a problem at this stage can think about it abstractly and can deal not only with objects and experiences but also with hypotheses.

Brunner, however, argues against the Piagetian notion that age, or state of biological maturity, sets a limit to what can be learned and in what way learning can occur. Bruner (1960) believes that, “the foundation of any subject may be taught to anybody, at any age, in some form”, and further, “...any subject can be taught effectively in some intellectually honest form to any child at any stage of development” (p.33).

Brunner (1990) also maintains that knowledge growth and the development of competencies, since they are situated within the individual, can develop independently of the situation within which they are used. However, Greeno (1989: 134-141) disagrees and, as quoted by Lutz & Huitt (2004: 67-90), maintains that thinking is the result of interaction between the individual and the environment. He argues that, “person/environment interactions are of such a complexity as to make attempts to discover generalised cognitive processes quite irrelevant”. This inclusion of the environment or situation into the learning equation is an important concept for this research study and is discussed further in Section 2.5.11.

Engineering activities are usually carried out in a team environment and this makes Bandura’s Social Learning Theory and the work of Vygotsky (1978) relevant to engineering education. According to Bandura (1989: 1-60):

“Learning would be exceedingly laborious, not to mention hazardous, if people had to rely solely on the effects of their own actions to inform them what to do. Fortunately, most human behaviour is learned observationally through modelling: from observing others one forms an idea of how new behaviours are performed, and on later occasions this coded information serves as a guide for action”.

Bandura’s belief that individuals learn by observing others, with or without reinforcement, also differs from the ideas of Piaget who did not believe that observation by children of the behaviour of others would precipitate the formation of new cognitive structures in the child.

Vygotsky (1978) believed that the process of learning required the agency of others and that the process was influenced by both one’s community and one’s culture. He

suggested that students can attain higher levels of thinking if they are guided by more capable and competent adults and he proposed a concept — the Zone of Proximal Development (ZPD). He defined the ZPD as the distance between the actual developmental level, as determined by independent problem solving, and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers. The ability to attain higher levels of knowing is often facilitated by, and may in fact depend upon, interaction with other more advanced peers, which for Vygotsky, unlike Piaget, are generally adults. Vygotsky's influence on the development of the theory of situated cognition, discussed in Section 2.5.11, was strong and of relevance to this proposed intervention. It too will lay stress on the social and collaborative aspects of cognitive development as a critical component for designing meaningful contexts for learners.

In traditional mastery learning, the assessment of students measures their progress towards the stated goals or learning outcomes of a course. However, as discussed above, from a pragmatic and constructivist point of view, the goal of the course is to improve the students' ability to use the subject matter in authentic, real-world, tasks. Therefore, for constructivists, evaluation must test the thinking *processes* of the student rather than assessment products, although as Bednar et al. (1992: 17-34) point out this does not exclude examination of the *content* of the domain. After all, experts in a field are experts because of their comprehensive knowledge of their specialist domain content.

Thus, from a constructivist viewpoint, there are two important evaluation criteria to be assessed and met if a student is to be considered to have made satisfactory progress. One is that the students' constructed knowledge of the subject is judged to permit them to function effectively in the discipline. For example, students can arrive at effective solutions to realistic, true-to-life, problems in the subject area. The second criterion is the observed possession by the students of the ability to defend their judgments and decisions.

These are powerful assessment criteria since they encourage students to advance from rote learning, in order to pass an examination, to developing their metacognitive skills — to think about their thinking. One obvious problem in utilising either one or both of these criteria in assessment is the issue of grading. Assuming that university schools of

engineering will continue to insist upon the summative grading of students, some way needs to be found to apply this traditional ranking method to the outcomes of constructivist evaluations. This is not an easy task. No two students are likely to make exactly the same interpretation of their learning experience or to apply their learning in the same way to a real-world problem with multiple answers.

Note: This issue is addressed somewhat in the course which is the focus this study by allowing a substantial component of the final course marks (50%) to be obtained from the completion of open-ended and indeterminate problems in the intervention.

2.4. Computer Technology and Engineering Education

2.4.5. Past Applications of Technology in Education

This section reviews the efforts that have been made over the years to utilise technology in the classroom and lecture theatre with the aim of improving learning. This examination will help to place in an historical perspective the current efforts to solve pedagogical problems by applying technology-based solutions such as computers and multimedia and to enable reflection upon what lessons might be learnt from the past.

Shortly after the advent of motion pictures in 1915 no less a personage than Thomas Edison felt confident to forecast that, “in ten years textbooks as the principal media of teaching will be as obsolete as the horse and carriage are now”, quoted by Gagné (1987). However, two decades later, Wise (1939) concluded that Edison's faith in film technology as a primary teaching resource was largely unfounded. Wise drew this conclusion after reviewing a number of studies concerning the effectiveness of learning through exposure to films. Although experimental groups exposed to films apparently did better in tests than control groups, Wise found that the research results were confounded by the variety of topics being covered and by outside circumstances such as students' pre-existing knowledge and the ability of the teacher. Wise adopted the view that films should only be used “as a supplement” to text and verbal descriptions supplied by the teacher. He placed stress on the need for adequate training of teachers in any new technology. A piece of advice still relevant today when applied to computing technology.

Following film, the next technology to be embraced in education was radio. With the invention of the transistor in 1947 by Shockley, Bardeen and Brattain radio receivers became truly portable and relatively cheap bringing about a tremendous growth in sales. This in turn generated an increase in the number, and variety, of radio stations. William Levenson, the director of the Cleveland public schools' radio station, claimed that, “the time may come when a portable radio receiver will be as common in the classroom as is the blackboard” (Cuban, 2001).

Hot on the heels of radio the next technology to be welcomed enthusiastically was television. By the early Sixties in America about US\$50 million had been spent on installing televisions in classrooms and by 1971 approximately US\$100 million had been spent on instructional programmes for delivery by television. As with previous technologies, educators were initially enticed by the high praise and vigorous promotion of the technology by its vendors and champions in the teaching profession, the government and school administrations. Eventually, however, the regular use of television in classrooms was as limited as that of previous technologies.

In the 1950's the prestigious behavioural psychologist, B.F. Skinner, developed his teaching machine which was a mechanical device designed to present to the learner a pre-programmed curriculum of instruction. It contained a list of questions on the topic being taught and the student was able to feedback to the machine what he or she believed to be the right answer (Skinner, 1968). Twenty years later Skinner recollected, perhaps ruefully, that he had commented at the time that “with the help of teaching machines and programmed instruction students could learn twice as much in the same time and with the same effort as in a standard classroom” (Oppenheimer, 2003).

Advances in semi-conductor technology led in the late 1970's to the emergence of the personal computer with a substantial growth in PC sales aided by the development of reasonably priced and relatively user friendly software applications and the WSIWG (What You See Is What You Get) graphical interface. As with earlier technologies, personal computers were greeted with enthusiasm as a tool which would revolutionise education.

In the early 1990's, the desire to use computers in the classroom was reinvigorated by the explosive growth of the Internet and the World Wide Web. Many parents and

educators hoped that the Internet would enrich computer assisted learning by connecting classrooms to the outside world. Thus, President Bill Clinton campaigned for “a bridge to the twenty-first century ... where computers are as much a part of the classroom as blackboards” (Oppenheimer, 1997: 45-62).

The failure, however, of earlier, much heralded technologies, to make much impact in the classroom or lecture theatre led many to sound a note of caution or even opposition. Oppenheimer wrote “There is no good evidence that most uses of computers significantly improve teaching and learning, yet school districts cut programs – such as music, art, physical education – that enrich children's lives, to make room for this dubious nostrum”. In commenting on the educational use of computers in universities, Cuban (2001) describes Stanford University's bid in the late 1960's to utilise the benefits of new technology. A fully-furnished television studio and a lecture theatre for 160 students was built with student-to-lecturer feed-back keypads fitted to each seat and a glass enclosed room where the sound, slide and film equipment could be operated by a technician during a lecture. By 1981 none of the original equipment, except the sound system, was being used. The reasons for this “swift decay” appear to be that only two out of thirty-five lecturers had ever fully used the equipment and that the technicians were abolished when funding for them ceased to be available. In addition the equipment often failed and funds were not available for repair or replacement.

Another trenchant critic of computers in the classroom is Clifford Stoll (1999), who says cynically that, “no funded pilot scheme for computer-aided instruction has ever been declared a failure”.

Cuban's, Oppenheimer's and Stoll's conclusions, that the utility and effectiveness of computers as teaching tools has been wildly overstated, has been criticised by some including Becker (2000). Becker argues that Cuban has not made enough allowance for the improvements in technology that have been made over recent years and that make computers a more useful teaching tool. For example, today's computers are faster and more powerful, software is generally more easy to use and students can become familiar with it more quickly.

Further criticism of Cuban's analysis comes from Shapiro (2001) who maintains that much of Cuban's research into the issues is shallow as a result of his use of small and

non-representative samples. Shapiro also points out that Cuban, by focusing on what happens in the classroom, seems to have missed, or not appreciated, the effect on students' education, attitudes and socialisation by their use of computers at home. This use of computers outside school, and the vast amount of data available from the Internet, he says, "opens up possibilities to both teachers and students that were not there a decade ago".

The most recent salutary lesson concerning the over enthusiastic adoption of computer technology in education was given by what Wall and McNamee (2004) call 'the rise and fall of e-learning'. As an example of the enthusiasm garnered by this new 'revolutionary' technology they quote John Chambers, of the network application giant Cisco, as promising in 1996 that, "The next big killer application for the Internet is going to be education. Education over the Internet is going to be so big it is going to make e-mail look like a rounding error". Between 1996 and 2000 many millions of dollars were spent by large corporations and educational institutions to create new educational content or convert existing teaching material for delivery over the Internet.

However, between 2000 and 2002 the inflated expectations for e-learning collapsed and with it the closure of a number of the learning software providers. In mid 2002 the share price of DigitalThink, a leading e-learning company, was trading at \$88.58, two years later the shares were priced at \$1.34.

According to Wall and McNamee the reason for the collapse was that the assumption by providers that 'if we build it they will come' was false. Much of what was touted as e-learning content consisted simply of existing text documents placed on the Internet, confusing the presentation of information with instruction, and was presented using inappropriate didactic learning structures. Also, the software was overpriced and most organisations found they were getting virtually no return for their investment. In their report on the stalled uptake of e-learning in America, Zemsky and Massy (2004), write that, "the hard fact is that e-learning took off before people really knew how to use it".

There were some successes, notably at IBM, GlaxoSmithKline and within the US military. Since the collapse in 2002 the e-learning software industry has been recovering slowly as experience in the effective design of e-learning grows and expectations of its educational value become more realistic.

An important factor in the likely uptake and use of computer-based learning, including the 'product' of this current research, is the attitude and experience of the end users, that is, students. Unlike other, earlier classroom technologies such as slide and movie projectors, and televisions, the classroom or laboratory computer is in the hands of the students both physically and figuratively. This radical difference in the technology means that the student customers can make individual decisions as to how much they wish to use the tool provided. The users are also relatively sophisticated and knowledgeable about the technology. Prensky (2001) says that today's university graduates will have spent less than 5,000 hours of their lives reading, but over 10,000 hours playing video games. Computers are an integral part of their lives.

In the academic arena expectations that e-learning and the Internet would allow cost-effective delivery of education to both on- and off-campus students were also generally disappointed according to McDonald (2007: 170-192). McDonald writes "It is now quite widely accepted that a sound pedagogical underpinning has been largely missing in these developments. A course does not become 'learner-centred' by going online; in some respects it becomes less so". Perhaps the most striking example of the gap between e-learning rhetoric and the reality of many implementations in the academic field has been provided by the recent expensive failure of the e-University in the United Kingdom (House of Commons, Education and Skills Committee, 2005).

Cairncross and Mannion (2001: 156-164) believe that too many designs focus on the computer and its interface rather than the pedagogy and Noguera and Watson (2004: 56-74) write that, "Many well-meaning efforts at integrating technology into the curriculum have failed because they begin with the technology, rather than with teaching and learning outcomes". Simonson (2003) makes the point that, "education is facilitated not by the medium by which the message is conveyed but by the quality and content of the message". This critical theme is echoed by Ahmed et al. (2003) who, in discussing computer-based teaching material, maintains that, "Unfortunately, too many ...universities just deliver course materials rather than create knowledge-building communities. Too many of them stress memorisation of facts that are tested with multiple choice questions, rather than having the learners actually use their new knowledge and skills as part of collaborative projects with other ...learners". Mayer (2001), one of the leading researchers and publishers in the field of multimedia design

and applications, in analysing the “largely unmet” hopes and expectations, also believes that the reason was that, “the driving force behind the implementations was the power of the technology rather than an interest in promoting human cognition”. Garrison and Anderson (2003) quote Ikenberry (1999: 56-64) who suggests that in most instances, “the [e-learning] revolution proceeds without any clear vision or master plan”. More recently Albirini (2007: 227-236) in a thorough critique of the use of computers in education has suggested that a new paradigm of instruction need to be developed to thoroughly restructure “education” and schools. No detail is given however as to what form this ‘reinvention’ would take.

There are of course many examples of the effective use of computer technology and of multimedia-based educational interventions and some these, in the domain of engineering, are reviewed later in this chapter.

2.4.6. Computer Technology and Practitioners

From the examples in the previous section it is clear that an important influence on the success or failure of computer-based education is the attitude of the practitioner and unfortunately, says Reeves (2000), there has been criticism of the way in which many educators typically utilise computers and apply multimedia technologies to their courses. In reviewing ‘the reality’ of computer-based learning Reeves et al. (2004: 53-65) maintain that “faculty members are not given sufficient time... and so fall back on using the technology to replicate, as faithfully as possible, the traditional course”.

Often those attempting to use computer technology in their teaching simply move existing text-based course material, substantially unchanged, to the computer screen. This tendency to ignore the opportunities presented by the unique characteristics of each media form has been documented and commented upon by Felder (2000: 326-327). Berg (2003: 7) comments that, “educational institutions are simply taking classroom methods and automating them with computers and other media. The reasons are many, but the approach is clearly wrong”. In some contexts, this simple transfer process is satisfactory if all that is required is an alternative option for access to course materials by students. However, if the intention is that a change of medium will make the material more attractive, stimulating or comprehensible, then this expectation is unlikely to be realised. In defence of teachers, however, Shortridge (2002) maintains that educators

who are not multimedia specialists have had little in the way of published guidelines to assist them in placing teaching material in cyberspace and of making the most of the opportunities presented by computer technology.

Ehrmann (2000: 40-49) believes that the rate of change of technology also is a major hindrance to educators attempting to utilise computers in their course delivery. This rapid obsolescence of both hardware and technical knowledge adding to what Hirst et al. (2005: 387-394) called 'the technology left in the cupboard' syndrome.

To assist in the dissemination and use of new computer-based technology Rogers (2003) proposed a theory of technology adoption in his book 'Diffusion of Innovations' and suggested that in order to facilitate the adoption of any innovation it should possess the following features:

- Advantage. The innovation conveys an advantage over existing ways of doing things.
- Compatibility. The innovation is compatible with existing needs and expectations.
- Simplification. The innovation makes life simpler, or at least, not more complex.
- Trialability. The innovation can be tried without a commitment to overhaul one's way of doing things.
- Observability. The innovation is observable on other sites to would-be adopters.

The impression can be gained by reading literature on the issue that many educators fear that too much use of multimedia teaching will divorce the student from their lecturer and his or her enthusiasm for their subject. However, McConnell (2001) has shown that it is possible to manifest the teacher's enthusiasm through the medium of a computer provided a thoughtful and structured approach to the multimedia environment is taken.

It seems clear that as a whole, academics, and particularly those in the sciences and engineering, are not averse to using computer-based interventions per se. What appears to be a rein on their use is a lack of clear guidance on how best to utilise computers in a teaching role and a dearth of clear evidence that the results will be worth the lecturer's time and effort. Another discouraging factor may be, as Anderson points out (2004), the "deafening silence" which generally greets the publication of educational research in general, and ways in which to improve pedagogical outcomes in particular. Successes in

this field seem not to be widely read or acted upon by other engineering educators. As Anderson comments, this is not a situation which seems to occur in other disciplines such as the sciences or medicine. In these fields the publication of new data, discoveries or insights generally initiates a significant amount of debate within the relevant community.

The history of the application of technology in the field of education indicates that any intervention developed as a result of this research study must, to be successful, utilise reliable and sufficient equipment and not require hardware of a specification that is higher than the norm for the organisation. This excludes, for example, consideration of the use of 3D virtual reality technology requiring head-mounted displays. The proposed intervention also, to be of practical use, must be easy and quick to implement, robust, simple to install and be capable of rapid updating to meet new course requirements and take advantage of developments in hardware and software.

Personal experience and discussion with academic colleagues indicates that a stumbling block to greater utilisation of computer technology to improve learning outcomes is no longer a shortage of equipment, unreliability or a lack of data storage. The main restriction appears to be a shortage of time to carry out the work of developing new teaching materials and lesson plans, and a suitable strategy for applying the technology.

Clearly the application of computers and computer based teaching methods and materials in the classroom requires thought and planning and, as demonstrated in this review of the history of technology and its use in the classroom, improvements in educational outcomes are clearly not guaranteed.

It can be observed that examples of new technologies applied to education, seem to all follow the same path. Initial high hopes about the benefits of the technology lead to a rush to implementation followed, a few years later, by disappointment that initial hopes were largely unfounded. These failures appear to be because the technology itself came to be the centre of the intervention rather than being considered as merely a tool to assist cognition. One lesson from this review of the application of technology to education seems clear. A more learner-centred approach must be adopted if technology-based interventions are to be successful in enhancing learning.

2.4.7. Applications of Computer Technology to Engineering Education

A review was carried out of the literature describing the application of computer-based multimedia and simulation technology to the teaching of manufacturing systems, and similar domains. Because of the ongoing advances in computer technology, and multimedia and simulation software, publications older than 10 years were excluded from the review unless they were considered of special note. Also excluded from the review were examples of computer-based learning concerned solely with demonstrating the operation and programming of specific hardware such as computer numerical machines (CNC). For example, the web-based CNC machine simulation programs by Ong (2002) and El-Mounayri et al. (2008: 183-189). These examples were excluded from the review because they serve a specialised training function. There is a category of management and manufacturing simulations which is concerned with the teaching of simulation software and simulation techniques per se for practitioners in the fields of systems analysis, and operations research. These examples also were not considered in this review. Manufacturing simulation tools based upon 3D virtual reality environments and requiring the use of specialised and expensive projection equipment and/or head-mounted displays were also excluded.

This section will review the examples of relevant educational interventions from the literature in the general sequence of: multimedia presentations, Section 2.4.7.1; simulation games (Section 2.4.7.2); and simulations (Section 2.4.7.3). However, it was not always clear which category was most appropriate for a particular example because of the substantial overlap between the types, See Figure 2-1. These overlaps were indicated by the authors' use of such terms as: multimedia; multimedia games; multimedia simulations; games; simulations; and simulation games.

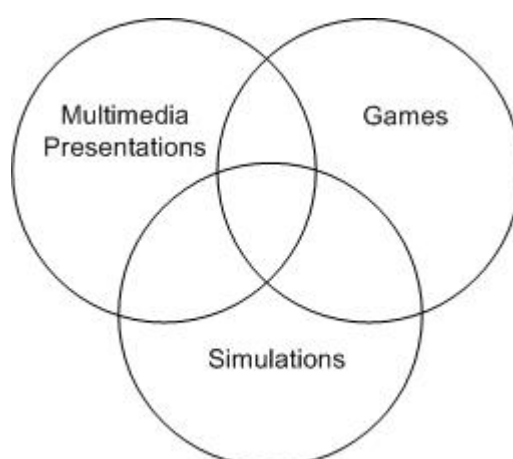


Figure 2-1: Overlaps Between Multimedia, Games and Simulation Applications

Also confounding the efforts at categorisation was the proliferation and variable use of the terms used to describe the interventions. Some authors used a particular term to describe different computer-based tools whilst others used the differing terms for the same tools. Often the term ‘game’ was used synonymously or in parallel with ‘simulation’. For example, Jensen et al. (1997: 491-494), (quoted by Maier, (2000: 135-148). Sometimes both terms are combined into ‘simulation games’ (Basnet, 1996, Bringelson et al., 1995: 89-92, Tangedahl, 1999).

The literature concerned with the design and application of computer-based learning in the fields of manufacturing systems and engineering/operations management consists primarily of descriptions, in conference proceedings and engineering journals, of the use of computers to illustrate manufacturing systems topics. These interventions utilise multimedia packages and, less frequently, simulation, or a combination of the two. Few of the publications describe in much detail any qualitative or quantitative assessment of the effects of the intervention. This may be because of the aims of the intervention exercises were solely to address, and resolve, particular local teaching problems with no ambition to make the exercises more formal or time consuming. Even fewer application examples give details of the pedagogical approach taken to the design and application of the intervention. There appears to be little debate in the literature by those engaged in applying computer technology to engineering education about the use of appropriate pedagogical frameworks upon which to build their designs, or of the application of appropriate research methods to examine the results of their interventions. This study is intended to be a contribution to this area.

2.4.7.1. Multimedia in engineering education

The term ‘multimedia’ first appeared in the 1970’s, (Ambron and Hooper, 1988) quoted by Richard Paske (1990), and was used to describe mixed, or hybrid, presentations combining text, graphics and film elements. Depending upon context the word may also be used to describe the software and hardware technologies used to deliver the material, typically computers, web browsers and the Internet,

The term *multimedia* is intended to emphasise that the various media that may be used are integrated with each other as opposed to *multiple media* which may only refer to the use of a range of media not necessarily interconnected (Schwartz and Beichner, 1999). For the purposes of this research the term multimedia will be used to describe a combination of textual, graphical (2D and 3D), visual (moving and still images) and animation media which are associated and connected and may be accessed in a non-linear fashion.

In the context of this review multimedia teaching interventions are defined as those computer-based programs which through linear or branching navigation allow a user to view information on a topic with a variety of media including computer graphics sound and video and animations. The user may also interact with the programme by entering answers to onscreen questions.

A number of examples in the literature of multimedia-based teaching tools applied to engineering education were examined. Four of the most relevant examples are described below. Other examples reviewed are summarised in Table 2-1.

The Multimedia Virtual Disk Drive Design Studio at the University of California, Berkley, uses interactive multimedia courseware to introduce students to the world of mechatronics in the form of a disk drive design problem. Students play the role of a project engineer and have to source the necessary information from a multimedia archive in order to build a new disk drive model. Decisions have to be made on the time to be spent on research, on consulting experts and on limiting costs. The student receives formative and summative feedback after the final product design is completed (<http://bits.me.berkeley.edu/mmcs/disk/disk.htm>), accessed 12/02/2008. No assessment procedure for the intervention’s effectiveness was reported but the student feedback was described as ‘very positive’.

Standen and Herrington (2000) describe the development and evaluation of a multimedia simulation for business students which was designed within a ‘constructivist shell’, to provide a real-life context and meaning. Video, sound and graphics are used to generate, what they describe, as “semi-realistic microworlds” to be explored by students in order that they may solve relatively unstructured problems. The scenario is that of a student employed in a part-time job in a commercial research organisation. The authors report that, “the opportunity to explore the microworlds is constrained by the resources [that were] available to develop complex artificial worlds”. They note that the form of interactivity present is somewhat artificial since the students ‘speak’ by selecting from a limited list of possible questions, although the authors suggest that students did not see these limitations as important. It could be argued, however, that the students’ relaxed attitude towards these limitations was influenced by what, from experience, they expect to encounter in the way of ‘realism’ when using typical educational multimedia teaching programs.

A computer-based multimedia and intelligent tutor system for teaching manufacturing is described by Woolf, Poli and Grosse (1999). The system aims to instruct students on the topics of ‘design for manufacture’ and on the manufacturing processes to be applied to the parts to be produced — injection moulding and sheet metal stamping processes. The authors report no quantitative results but maintain that student evaluations showed that the multimedia tutors “were as effective as traditional lecture instruction”.

Kelly (2002) describes the challenge of teaching abstract scientific principles and reports on the development of a multimedia, virtual ‘Power Plant’, accessible via the Internet, which is designed to help students understand and apply thermodynamic principles in realistic conditions. The intervention consists of computer screen representations of the various features of the power plant—control room, design office, etc. which contain text, photos, schematics and animations. Students are given the challenge of optimising the ratio of fuel input versus power supply and demand. The intervention’s pedagogical design was said to be based upon situated learning principles. Situated learning as a pedagogical framework is described in more detail in Section 2.5.11.

Educational interventions which are designed solely around computer-based multimedia (of the kind reviewed in the previous section) do not appear to offer the prospect of satisfactory solutions to the issues which underlie this research, despite the reported enthusiasm of the students. The use of a computer-bound multimedia presentation of teaching materials, of itself, does not seem to provide a sufficient level of immersion or fidelity to assist with meeting the desired goals of improved delivery of complex domain materials and an increase in student motivation and engagement.

The use of teaching interventions based solely on computer-centred multimedia programs such as the Virtual Disk Drive Design Studio, regardless of how well designed the interfaces are, are unlikely to provide sufficient ‘suspension of disbelief’ (see Page 65) for students to be willing to accept that they are interacting with a believable organisation.

Ironically it is the interactive features of most multimedia interventions which lower the level of immersiveness. As Plowman (1998) suggests, it is at the “foci of interactivity” that the thread of the story or narrative thread can be disrupted. These foci often require the user to stop and choose from menu options to navigate a path through the presentation and affect the narrative flow. This can lead to the task of navigation becoming the focus rather than the content of the material. This ‘sidetracking’ focus prevalent in multimedia interventions would be a barrier to full immersivity and suspension of disbelief in the proposed virtual enterprise.

A less computer dominated approach would seem to offer the possibility of greater involvement by users and so the literature concerning simulation games was examined to determine if the reports of this methodology offered a better prospect of immersion. The results of this review follow.

2.4.7.2. Simulation games in engineering education

A simulation game may be defined as an activity which simulates a real-world situation in which decisions must be made and contains, in addition, game-like elements such as scoring, payoff, and often, conflict (Deshpande and Huang, 2009, Netherwood, 1996). Games are also generally short, one-shot, exercises designed to illustrate a single concept or procedure. They tend to be demonstrations of a particular principle or

heuristic and lack the ability to vary the number of input parameters that a 'pure' simulation might possess, resulting in a limited scope for re-adjustment of the scenario.

Because of the short-term nature of most simulation games, attempts to build an immersive scenario are not required and they are often designed so that students may have fun when using them; e.g. the 'Beer Game' (Sterman, 2008) which demonstrates supply chain instability and 'The Great Crapshoot' (Jacobs, 2007), the aim of which is to maximise product deliveries whilst at the same time minimising inventory.

Simulation games may or may not be computer-based. For example the 'Beer Game' is available in either a software or a hardware version with dice, tokens, record sheets, etc. An advanced version of the Beer Game was developed by Sparling (2002: 334-342) and incorporated additional planning and forecasting techniques which were modelled using spreadsheets.

Simulation games can range in complexity from a board-game type of simulation utilising dice and counters such as the 'The Great Crapshoot' through to a few decision rules incorporated in a relatively simple spreadsheet to handle data analysis (Basnet, 2001), through to complex spreadsheets (Tangedahl, 1999), and discrete step-by-step games (Baranauskas et al., 2000: 162-169, Sanderson et al., 1997). The most complex games operate in real-time where the students must maintain ongoing contact with the simulation to deal with the evolving scenario of the game (Chi et al., 2004: 2103-2106). Sometimes these more complex simulations have suddenly changed ground-rules or different operating parameters substituted by the teaching staff to keep the students on their toes and simulate the variations and vagaries of a real environment (Chi et al., 2004: 2103-2106).

Most of the 'educational' games and simulation-games reported in the literature are designed for use in the fields of business and operations management. However, manufacturing systems components are the focus of a game developed by Cox & Walker (2004: 3-19). They believed that the concepts of production line planning and line balancing were difficult to understand for students who had no practical manufacturing experience and developed the 'Poker Chip Game' to help students understand the concepts. This intervention is a multi-product, multi-customer, stochastic

supply chain network designed to teach students about the difference between ‘pull’ and ‘push’ inventory policies on supply chain performance.

However, in general, games are generally of a ‘one off’ nature rather than being an ongoing and integrated part of the students’ learning experience over a long period. Nevertheless they do seem to generate enthusiasm (Elgood, 1996, Sterman, 2008). They can also improve knowledge retention according to a review of the literature carried out by Randel et al. (1992). They described fourteen studies measuring knowledge retention which reported significant results in favour of the groups exposed to simulation games. Ten of the studies reported significant improvement in retention (in periods ranging from 10 days to 8 weeks) whilst four found no difference in retention between the group exposed to the game and the group which was not. The same authors report that in 12 out of 14 studies, students reported more interest in the material delivered via simulation and game activities than in material delivered by more conventional, lecture methods.

2.4.7.3. Simulation in engineering education

Simulation is defined by Kelton, et al. (2007) as “a broad collection of methods and applications designed to mimic the behaviour of real systems”. Hertel (2002), on the other hand, defines simulations from an educational point of view and says they create a complete environment within which students can apply theory and practice skills on real-world issues and allow teachers to integrate multiple teaching objectives in a single process. He says that they motivate students, provide opportunities for active participation, promote deep learning, develop interactive and communication skills, and link knowledge and theory to applications.

When it comes to applying simulation to manufacturing systems education the techniques described in the literature range from very simple desktop methods to computer-based virtual factories.

Gredler (2004: 571-581) describes the important characteristics of simulations as:

- Being adequate models of complex real-world situations with which the student interacts (the simulation’s validity).
- Containing defined roles for the participants which carry with them responsibility and constraints.

- Presenting environments rich in data that permit students to execute a range of strategies.
- Feedback from their actions is given to participants in the form of changes in the problem or situation.

Note that simulation validity is defined by Zeigler, et al. (2000) as “the degree to which the model faithfully represents its system counterpart”, whilst the term ‘fidelity’ is often used to describe the combination of validity and model detail.

Simulation allows the educational intervention to provide opportunities for students to deal with ill-defined problems in which the value of the desired goal is not clear at the outset. Simulations also provide feedback to the students on the quality of their decisions in the form of changes in the model, which may be desirable or undesirable outcomes e.g. surplus stock or late deliveries. This is in addition to any summative feedback they may receive from the lecturer.

2.4.7.4. Simulation applications - examples

A review was carried out of the literature concerning the application of computer-based simulations to the teaching of manufacturing systems, and similar disciplines, and six of the most widely referenced and most relevant examples are described in this section.

Further examples of engineering-based simulations are summarised in Table 2-1.

There are a number of manufacturing system simulations reported in the literature which are produced by professional practitioners in order to deal with their organisation’s own problems or issues, and are not designed for use in undergraduate education. These have not been included in the review. Examples of these corporate simulations are: ‘Using Internet Technology For Design Of Facilities And Material Handling Systems’ and ‘Virtual Machine Models’ at Georgia Institute of Technology (Bodner et al., 1997: 61-66); and the ‘Virtual Factory for Manufacturing Process Visualization’, Curtin University of Technology (Zhong and Shirinzadeh, 2008). The literature also has a number of examples of non computer-based simulations which use a specific hands-on, table-top tactile approach. These simulations are often designed to simulate a particular technique in manufacturing systems management, such as ‘lean’ manufacturing and involve the production and manipulation of a physical product, e.g. paper aeroplanes (Billington, 2004: 71-76), Lego cars (Fang et al., 2007) or lampshades

(Ozelkan and Galambosi, 2008). In general these exercises are designed for company in-house training and have not been included in the review.

A manufacturing systems simulation widely referenced in the literature is that developed by Standridge (2001: 1613-1618). In his paper Standridge describes a computer-aided teaching studio designed to cover, in depth, the topics of modelling and simulation in manufacturing systems. Emphasis is placed on the use of real case studies in areas such as 'push' versus 'pull' manufacturing strategies, supply chain management and materials handling. Standridge's work is designed to integrate conventional lecture material with computer-based simulation. Systems simulation projects are presented wherever possible as problems based upon real case studies in the areas of basic systems organisation, lean manufacturing, materials handling and supply chain management. However, in the studio there is no attempt to integrate the various case studies into a coherent scenario or to replicate the look and feel of a manufacturing organisation.

In the 'Della Steam Plant Case Study' by Raju and Sankar (2000) the aim is to assist engineering students to develop higher-level cognitive skills such as problem identification, critical thinking, and problem solving. The courseware uses video clips, audio messages, still pictures, and textual material to present a case study on the fault analysis and repair strategies required in a steam turbine plant. The authors do not report any detailed qualitative or quantitative evaluation of the program but state that it received favourable responses from the students. They say that comments from the students, "were sprinkled with phrases such as 'real life', 'real situation', and 'real world'."

One of the most widely referenced works on virtual factories applied to manufacturing engineering is by Dessouky et al. (2000: 167-180). In this publication Dessouky points out that historically, "manufacturing engineering education has focused on teaching mathematical models using simplifying assumptions that can mask the realities of complex manufacturing systems". However, he maintains that recent pedagogical approaches to manufacturing education have attempted to take a more holistic view of manufacturing operations and he describes a collaborative learning network called the Virtual Factory Teaching System (VFTS). The system is one which allows students

working individually, or in teams, to build factories, forecast product demand and plan production. Students may enter various numbers of machine entities and manufacturing parameters in an on-screen dialogue box and the representation of these parameters appears in an adjacent window. The system contains three stand-alone modules for scheduling, planning and forecasting.

Following the initial publication of Dessouky's paper in 2001 a further paper by was published by Rickel and Dessouky et al. (2003) in 2003. This reported on subsequent developments of the VFTS scheme to include support for the simulation of job-shop operations in addition to the original hybrid-flow shop, and the integration of the forecasting, planning and scheduling modules so that the results from one could be used as input to the next.

However, the main focus of Rickel and Dessouky's additional paper was the description of the development and application of an automated laboratory instructor (ALI). ALI uses in-built knowledge rules to monitor the simulations carried out by students in order to test students' understanding of the processes. For example, when a student runs a new, amended, simulation ALI compares the values of the new dependant and independent variables that are input by the student to those of the previous simulation. If more than one independent variable has been changed at once ALI will suggest that it is preferable to change only one variable at a time.

An important difference between Dessouky and Rickel's work and the intervention planned for this research is that the VFTS does not attempt to reproduce a realistic, overarching, working organisation scenario with a coherent product range, associated virtual company documentation or other realia.

Rafe et al. (2001: 18-23) considered the application of a distributed virtual laboratory (DVL) to deliver continuous education and training in manufacturing related disciplines via the Internet. Their paper noted the importance of continuing education for manufacturing engineers and presented their Virtual Laboratory as a means of presenting material in a manner that was aligned with the experiential learning style (often preferred, they say, by those working in manufacturing industries) and was also suitable for distance learning. The DVL is described as employing a networked client-server approach using readily available information technologies and incorporates an

interactive module called the interactive virtual laboratory (IVL). Selection of this component from an icon on the computer screen causes a new browser window to appear within which a computer generated 'actor' can be used to model ergonomic and work study issues.

In seeking to address the problem of a lack of effective topic integration in the teaching of production management and control, Lindeque and Kruger (1988: 53-62) developed a computer-based training simulator (CIMSIM) containing most of the usual information processing and decision support features of an industrial, computer integrated manufacturing system (CIM). CIMSIM contains material requirements planning (MRP), capacity requirements planning (CRP) and shop-floor scheduling modules. Students are assumed to be in control of a manufacturing cost centre and are expected to make informed decisions in order to produce viable, weekly shop-floor production schedules. However, no attempt is made to place the simulator within the immersive context of a virtual company or to include activities other than those of production control.

In papers on the 'Interactive Learning Modules (ILM)' project at Rensselaer Polytechnic Institute, Sanderson (1997) and Millard (2000: 1042-1047) reported on the development of multimedia software aimed at improving the teaching of design and manufacturing. Multimedia tools were used to create an environment which simulated the product development process. The stated goal of the ILM project was, "to convey to engineers and managers the experience and principles of strategy and decision-making, focusing on the interrelationships among design, manufacturing, and marketing". The scenario of the ILM revolves around 'Cybertronics Incorporated', which is described as "A fictional enterprise, engaged in the development of electronics products, in which the user assumes the role of product designer, manufacturing engineer, marketing expert, and product manager. In working through decisions required in product development, the user addresses the trade-offs between product performance, cost, quality, and time-to-market". This scenario provides a framework for experiential learning of design and manufacturing principles based upon case studies of real organisations.

The authors report that in one comparison of two classes on the topic of circuit analysis, students exposed to the studio intervention performed slightly better, and reported

greater satisfaction, than those that were not. The median exam score for intervention students was 79.7 and 74.3 for a similar group of students in the non-intervention group. On a scale of 1 to 4, students rated the lecture version of the course at 3.0 and the studio version at 3.6. Asked if the course increased their knowledge and skills in the subject, the students rated the studio version at 3.8 and the lecture version at 3.4.

The ILM scenario does not attempt to deal with topics such as plant layout methodologies, ergonomics or constraint scheduling. No attempt is made to make the Cybertronics Incorporated scenario encompassing or immersive.

The table (Table 2-1) on the following pages contains a number of multimedia and simulation based educational interventions in the disciplines of manufacturing systems and operations management. These were reviewed during the literature search carried out to investigate existing research in the field and to ensure no duplication of effort with this research work. The table contains a brief description of each intervention and a comment regarding its commonality, or differences, from the proposed intervention for the manufacturing systems course.

Table 2-1 Current Examples of Virtual Factory/Lab Research

.

This review of the literature describing the application of computer-based multimedia simulations and games to engineering education has revealed a broad number of approaches. It was noted that the published research describing these educational interventions generally does not include significant details of student reaction to the intervention or to its pedagogical benefits. Nor does most of the published research include details of the learning philosophy adopted as a framework for the intervention. The level of immersion and scope of the interventions as described by the publications appears to be limited.

There seems to be no evidence in the literature at the present moment of examples of investigators developing an integrated, narrative based, immersive multimedia learning intervention applied to the design and management of manufacturing systems such as the one proposed in this research work.

In order to fill this gap in the research literature this current work will seek to design an intervention which is immersive and a valid enterprise and includes an appropriate learning philosophy as an integral part of its design and implementation.

The following sections will investigate the use of narrative, student approaches to learning and pedagogical models of learning to assist in meeting these design objectives.

2.5. Models of Instruction for Virtual Environments

2.5.8. Introduction

The purpose of this section of the literature review is to assist with developing the theoretical foundation upon which the design of the proposed teaching intervention will be based. The way that learning is thought to occur has an important bearing on the design of the intervention since the goal is to assist students to change what they know in the most effective way possible.

Many theories have been proposed over the years in attempts to describe the mechanism, or mechanisms, by which humans learn. Curzon (2004) defines learning as, “the apparent modification of a person’s behaviour through his activities and experiences, so that his knowledge, skills and attitudes, including modes of adjustment, towards his environment, are changed, more or less permanently”, whilst Stones (1994:

348) suggested a definition of teaching theory as, “the bodies of principles that have explanatory power and the potential for guiding teacher action”.

2.5.9. Educational taxonomies

In the early 1950's Benjamin Bloom, together with some collaborators, developed a classification of educational objectives (1956). This became a taxonomy which included three overlapping domains — the affective, psychomotor, and cognitive (Anderson et al., 2001). The cognitive domain, the one of most interest to this research, covers the spectrum from the simple memory recall of facts to complex evaluation of competing alternatives.

The levels within the cognitive domain are:

Level 1, Knowledge: the basic ability to recall information without necessarily understanding the material being remembered.

Level 2, Comprehension: Comprehension of the meaning, translation, interpolation, and interpretation of instructions and problems. Students can state a problem in their own words.

Level 3, Application: The student can apply what was learned in new situations and select the appropriate response unprompted.

Level 4, Analysis: The student can distinguish between facts and opinion and can split the organisational structure of a concept down to its component parts in order to better understand it.

Level 5, Synthesis: Here the student originates and combines ideas into a concept or proposal that is new and original.

Level 6, Evaluation: The learner is able to evaluate and assess ideas and concepts utilising specific standards and criteria.

The importance of Bloom's taxonomy is that it helps to classify the required learning outcomes of the proposed intervention and suggests some measures that can be used to identify different stages or levels of learning and, although not stated explicitly, suggests that different theories of learning might be adopted for different levels. The work of Bruner (1990) reminds us that lectures and assignments must focus on the level of cognitive skills which students are to be guided to use. Thus, if it is required that students are to be able to synthesise what they have learned to produce novel solutions to a problem they must be given assistance by ensuring that lectures and assignments give the students practice at the appropriate level of Bloom's taxonomy. The use of

Bloom's taxonomy is commonplace in the design and development of computer assisted instruction and has a place in the development of this educational intervention.

In a discussion relevant to this intervention Johnson & Johnson (1989) and Sherwood (1990: 1081-1086) have suggested that verbal interactions between students when using simulation software facilitate higher-order thinking and relativistic thinking as students readily interact with their peers to solve problems.

2.5.10. Gagné Events of Instruction

Gagné (1970) places importance on specifying a hierarchy of learning tasks whenever a rule learning or problem solving task can be broken-down into pre-requisite and simpler capabilities. We should be aware of the importance of mapping the sequence of learning, "to avoid the mistakes that arise from omitting essential steps in the acquisition of knowledge of a content area". He writes, "The analytic process may be carried out, if desired, until the simplest learning types (signal learning and stimulus response, chains, discriminations) are reached and identified". Gagné's conditions of learning theory, as quoted by Kearsley (1994), also specifies a sequence of nine instructional events and their corresponding cognitive processes as follows:

1. Gaining attention (reception).
2. Informing learners of the objective (expectancy).
3. Stimulating recall of prior learning (retrieval).
4. Presenting the stimulus (selective perception).
5. Providing learning guidance (semantic encoding).
6. Eliciting performance (responding).
7. Providing feedback (reinforcement).
8. Assessing performance (retrieval).
9. Enhancing retention and transfer (generalisation).

Gagné's work, although typically applied to the business of instructional design for fully computer-based multimedia learning programs, has important ramifications for this current research. Incorporating these activities into a teaching intervention should provide an optimum sequence for learning and can act as template for computer-aided learning interventions and instructional design development.

In a discussion of educational games design, Gunter and Kenny (2006) point out that a critical part of Gagné's events of instruction is continuity in the flow of information. It

follows that the nine events have a natural application in video games, and by inference, multimedia and simulation teaching tools. Gunter and Kenny offer each of Gagné's nine instructional events mapped with their associated games/simulation analogue as shown below:

1. Gain attention - Scenario exposition.
2. Inform student of objectives - Problem setup.
3. Stimulate recall – Refer to previous task.
4. Present stimulus/lesson – Show relevance and offer challenge.
5. Provide learner guidance - Provide direction.
6. Elicit performance - Elicit action/decision.
7. Provide feedback - Discernable outcome.
8. Assess performance - Task feedback.
9. Retention and transfer – Review simulation.

Clearly, according to Gagné (1970), relevant and continuing student interactivity is a critical feature of instructional design. Gagné's influence has helped to ensure that emphasis is placed upon on the learner rather than on the instructional materials. The principle being to take care that the design of the proposed multimedia intervention does not take centre stage at the expense of the learners' requirements, although, as Richey points out (2000), Gagné's learner involvement does not stretch so far as to give learners control of the instructional process and total individualisation, as constructivist theorists would advocate.

Later researchers Lave and Wenger (1991) suggested a model that placed emphasis upon the social and collaborative aspects of learning called *situated learning*, which will be described in Section 2.5.11 below.

2.5.11. Situated Learning

Situated learning, or situated cognition, has become an important pedagogical theory since it was first proposed by Brown, Collins and Duguid in 1989 (1989: 32-42).

Although, as Herrington and Oliver (1995: 253-262) point out, Resnick pre-empted the theory of situated learning in 1987 (1987: 13-20) by proposing that 'bridging apprenticeships' be designed to bridge the gap between theoretical learning in the formal instruction of the classroom and real-life application of the knowledge in the

work environment. This proposal was based upon the theory that understanding develops through applying knowledge within the context of a relevant culture.

Brown, Collins and Duguid (1989: 32-42) and Rogoff & Lave (1984) maintain that items of information cannot be remembered as freestanding and abstract entities of information to produce a successful learning outcome unless they are situated in a real-world context in which the problem is relevant. This general theory, about how individuals acquire knowledge, is built upon earlier work by Bandura and Vygotsky as reviewed in Section 2.3.4.

Situated learning theory and constructivism appear to be mutually compatible and the approach might be described as 'pragmatic constructivism'. Lave and Wenger (1991) developed the idea that learning, "is a process of participation in communities of practice, participation that is at first legitimately peripheral but that increases gradually in engagement and complexity". That is, learners initially participate on the fringes of a community of practitioners, e.g. professional manufacturing engineers, moving, with more experience, toward full involvement. Learning is not just the acquisition of knowledge but also a process of social participation.

Situated learning theory proposes that knowledge and skills are learned in the contexts that reflect how knowledge is obtained and applied in everyday situations. It requires that enquiries into learning and cognition must take serious account of social interaction. In this context *situated* does not mean in a particular physical setting but in an authentic and relevant context. Also in this context, *social* interaction is taken to mean acting appropriately to conform to the norms of the relevant social group, e.g. fellow students, professional organisations, co-workers, etc.

As an example of the importance of learning in context, Brown, Collins and Duguid quote Miller and Gildea's work on teaching vocabulary (1987: 94-99). Miller and Gildea note that by listening, talking and reading in context the average 17 year old will have learnt about 5000 new words per year over 16 years. In contrast those learning vocabulary by utilising abstract definitions and sentences taken out of context (a typical approach to teaching a new language) only average about 150 new words per year. In addition, many of the new words, although capable of re-call, are not effectively used in

practice. To make the point about the importance of context they give the following examples of students' use of words acquired out of context:

Me and my parents correlate, without them I wouldn't be here.

I was meticulous about falling off the cliff.

Bednar (1992: 17-34) also suggests that learning always takes place within some context and that the context forms an inexorable link with the knowledge embedded in it. In the article quoted, Bednar is dealing with instruction in schools; however, his remarks seem to be equally applicable to undergraduate learning in the engineering field.

Traditionally, in universities teaching has consisted primarily of the extraction of facts from what are considered to be the essential concepts of a discipline which are then distilled into a condensed, decontextualised form for an itemised curriculum. However, knowledge is not simply a collection of facts or figures although facts, figures and descriptions are how individuals categorise, or map, what they know. But, as Clancy (1995: 49-79) points out, "the map is not the territory... human knowledge should be viewed as a capacity to co-ordinate and sequence behaviour, to adapt dynamically to changing circumstances".

Bednar believes that the reason why much of what is learnt fails to transfer from school, or university, to non-school environments, or even from one topic to another, is due largely to the fact that the school context in which the subject matter is taught is substantially different from the non-school environment where the subject matter might need to be applied. He refers to Spiro (1995) who argues that it is a mistake to simplify the context of what is taught to suit the school (university) setting. Rather, as far as possible, the complexity of the relevant environment must be maintained to help the student to understand the subject matter and how it is embedded in the multiple complex environments in which it is found. This is not to say that, for example, a student would be confronted with a context which was as complex as that experienced by an expert in the subject matter. The learning environment must vary in complexity to match the current expertise of the learner.

Herrington (2006: 3164-3173) has defined the critical features of situated learning for computer-based instructional design and writes that situated learning environments will:

- Provide authentic context that reflects the way the knowledge will be used in real-life.
- Provide authentic activities.
- Provide access to expert performances and the modelling of processes.
- Provide multiple roles and perspectives.
- Support collaborative construction of knowledge.
- Provide coaching and scaffolding at critical times.
- Promote reflection to enable abstractions to be formed.
- Promote articulation to enable tacit knowledge to be made explicit.
- Provide for integrated assessment of learning within tasks.

The following diagram, Figure 2-2, shows the how the critical features of situated learning are constituted within the three mutually linked elements of the learning process.

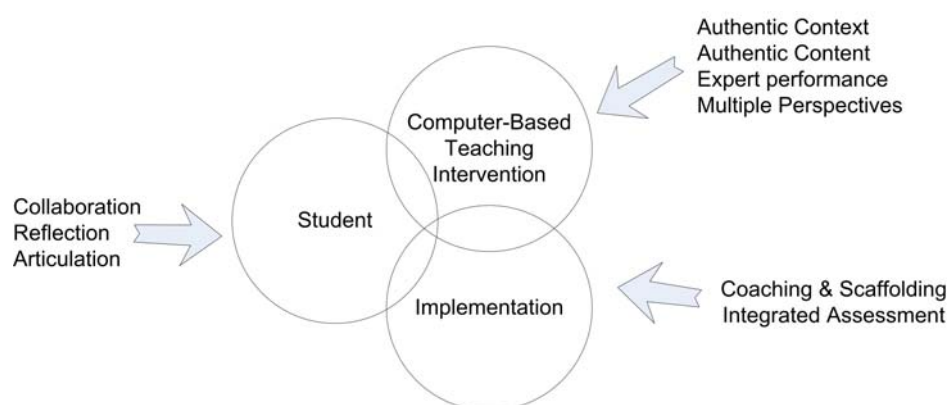


Figure 2-2: Elements of Situated Learning (Adapted from Herrington, 1996)

Whilst situated learning has become a well used methodology it has been subject to some criticism. The theory of situated learning can perhaps be criticised on two grounds. The theory insists that it makes no sense to talk of knowledge that is abstract or taken out of context. However, it would seem that there are circumstances where learning could take place in abstract and/or decontextualised situations. For example, one can glean scraps of information from watching a TV quiz show. Secondly, new knowledge and learning are described as being acquired through being located in effective communities of practice, however, there may be times when the community of practice is weak or dysfunctional and it seems unlikely that, even in this event, the acquisition of new knowledge would be totally inhibited.

Anderson, Reder and Simon (2000) believe that, “claims from the situated learning camp are often inaccurate.” They write that the central claim of situated cognition; that action is grounded in the concrete situation in which it occurs is often exaggerated to assert that ALL knowledge is grounded in this way. Whilst they agree that often heuristically-based skills practiced in real-life situations, e.g. making price comparisons whilst shopping, often do not proceed from classroom-based techniques, the converse does not follow. That is that arithmetic procedures taught in the classroom would never be used in the supermarket. They go on to say that, contrary to Lave (1988), who implies that skills taught in schools do not contribute to performance at work, there are numerous studies that show modest to large correlations between achievement in school and on-the-job performance. They refer to studies by Hunter and Hunter (1984: 72-98) and Boissiere, Knight and Sabot (1985: 1016-1030) in support of their view. Anderson, Reder and Simon also believe also that the second claim of situated cognition; that knowledge acquired in one context will not transfer and be applied in other contexts, is also exaggerated and maintain that whilst there are dramatic failures of transfer there are also dramatic successes and they quote Brown (1994: 4-12) and Brown and Campion (1994: 229-270) in support.

Despite the criticisms that some proponents of situated learning have exaggerated the aspects of authenticity and transfer, the methodology appears to present a valid framework for the design of the proposed intervention and it will incorporate the elements of authentic context, authentic content and collaboration required.

The learning theories examined in this chapter, behaviourism, cognitivism and constructivism, support different kinds of learning. As Ertmer and Newby (1993: 50-70) suggest, there is no *best* learning theory. Which approach is most appropriate depends upon the learners, the learning objectives and the learners’ prior knowledge. Different learning approaches may be adopted as learners’ expertise in the topic develops, the material becomes more complex and learning objectives change from the students gaining simple facts (Bloom’s taxonomy category of ‘knowledge’) to solving complex problems (Bloom’s taxonomy category of ‘synthesis’).

The planned intervention for the manufacturing systems course will include all of the necessary material for satisfactory coverage of the programme topics and the

achievement of the learning outcomes. The first step (phase A) is to present material which consists of basic information, generally new to the students, about the topic being covered. For example, the course which is the focus of this research could begin by covering the topic of 'efficient manufacturing plant layouts'. The initial material would describe why an efficient layout for a factory is essential for safe and profitable operations and why established layouts need occasionally to be re-examined and revised. This factually-based and procedure-orientated material would lend itself to delivery in accordance with behaviourist principles as it may be broken down into small units and specific learning objectives may be set. Assessment would be carried out in a timely fashion with short, in-class quizzes and with feedback given promptly.

Next the various heuristic methodologies for developing a viable solution to a manufacturing systems layout problem would be explained (phase B). This section of the topic is best delivered utilising recognised cognitive principles because students will be required to organise many broadly sourced and disparate pieces of information into a large, conceptually linked and interconnected body of knowledge. Using this knowledge they can draw analogies, make inferences, and generalise the information to new content areas (McGilly, 1994).

Finally, before proceeding to the next topic, students may be given the task of laying out the virtual organisation's manufacturing plant on a new site utilising one or more of the heuristic tools they have been shown (phase C). Initially solutions are developed by students individually. Once they are confident that their solution meets all, or most of, the requirements of the virtual factory management they discuss their solution, and those of their team colleagues, at a design team meeting. At this meeting students negotiate a recommended joint solution incorporating the best ideas from the individual proposals. This section of the topic coverage is delivered utilising constructivist principles as learning is occurring within an authentic context and generally with colleagues with the teacher adopting the role of mentor rather than lecturer, c.f. Schunk's (2004) definition of constructivism. Assessment will be carried out on overall success of problem solving and task completion, the team dynamics and its level of negotiation and discussion.

A similar three-step process might apply throughout the rest of the course, e.g. elaboration of the standard theory for the topic, examples presented using multiple media, methods of attacking problems which arise in the topic and finally an exercise, with the use of professional software where relevant, to solve a typical problem and finally, a connection made between current knowledge and information from the previous task.

This methodology is readily transferrable to alternate versions of the intervention designed to assist in the delivery of courses in other ill-defined domains such as engineering design and engineering management.

The application of objective-behaviourist and cognitivist principles to the phases A and B described above is relatively straightforward and the procedure is described in more detail in Chapter 4. The use of a constructivist view of learning in phase C, the core of the immersive intervention, is however more complex because of its subjective nature (Mergel, 1998) and a learning framework, situated learning, must be adopted within which these design principles can be applied.

2.6. Factors Influencing Student Learning

2.6.12. Narrative

This section of the literature review will examine the literature concerning the use of narrative as a tool in education. It will, in particular, review its application to immersive simulations and draw conclusions about its importance to, and effects on, the design of the planned teaching intervention.

In seeking a definition of narrative, that of Plowman (1999: 310-317) appears to be a useful and practical one and will be adopted for this work. She describes the essential elements of narrative as:

“... a macro-structure which creates global coherence, contributes to local coherence, and aids recall through its network of causal links and signposting. The structure provides a linear dynamic which can accommodate diversions and tangents and allows learners to maintain their plans and goals. It has both cognitive and affective impact, performing an essential organising function for the learner by shaping the creation of meaning from texts of all kinds”.

In this review the words narrative and story will be treated as synonyms as suggested by Polkinghorne (1988).

“I liked the drugs one because it had a story,” was the reaction of a thirteen year old during an evaluation of ‘What's the Hype?’, an interactive health education module for Australian adolescents and quoted by Bearman (1997) in a paper presented to the 1997 ASCILITE conference. This response is a classic example of how the use of narrative (from the Latin root ‘narrere’ which means to ‘make known’ or ‘describe’) can engage students’ attention. Narratives or stories can have a powerful and spellbinding effect on children and adults alike, as anyone who has fallen under the spell of a professional story teller can attest.

Samuel Coleridge, when discussing his plans to produce poetry, for the ‘Lyrical Ballads’, used the phrase, “willing suspension of disbelief” to describe an audiences’ capacity, “to accept the premises of a work of fiction, even if they are fantastic or impossible”. The phrase also refers to the willingness of an audience to overlook the limitations of a medium, so that they do not interfere with the illusion. For example, Shakespeare’s successful use of a front-of-stage narrator clearly divorced from the characters and the action on stage, to provide essential background information to the audience. However, “suspension of disbelief is a quid pro quo: the audience agrees to provisionally suspend their judgment in exchange for the promise of entertainment” Wikipedia entry (Anon, 2006) or, in the case of the proposed teaching intervention, for learning.

Although people will, under many circumstances, suspend disbelief when listening to, or watching a story unfold, the design of the virtual enterprise teaching intervention must be careful not to allow inconsistencies that may compromise this suspension. For example a student engineer at the cinema may be happy to accept that Superman, by donning a cape, is able to break all the laws of physics and fly, yet the same student would probably be unhappy were a scene to show an obviously fake machine. It appears that audiences are willing to accept the unreality of a narrative and to suspend disbelief as long as any premise they are asked to accept is intentionally placed in the narrative by the provider. However, they are not prepared to accept situations, characters or details that appear to be inconsistencies introduced by mistake.

Bruner (1996) believes that narratives are vital for humans and that narrative is “a mode of thinking, ...a structure for organising our knowledge, and a vehicle in the process of education, particularly science education”. He argues that in education the sciences have severely neglected the use of narrative and it seems likely that the same criticism can be levelled at engineering. For example, Rickel’s et al. (2003) web-based Virtual Factory Teaching System, Kline’s (2005) ‘Penny Fab’ production line simulation, and the Interactive Virtual Factory by Kesavadas et al. (1999). These interactive simulations of manufacturing operations present models of real-life operations but the scenarios do not provide a detailed and consistent narrative framework throughout their design.

Abrahamson (1998: 12) believes that storytelling forms the foundation for education and claims that putting teaching material into a form of narrative helps students to think in a crucial manner and make their learning experiences more personalised. He does not review the issue of motivation but one could expect that increased personal identity with the material would also increase student interest, engagement and motivation.

In support of the contention that narrative can give useful support to simulations and interactive teaching interventions, Bearman (1997) quotes Clarke and Craig (1992: 19-30) as believing that, although interactivity may provide gains in learning, it is narrative that serves to keep the learning experience focussed. She refers to her own experience showing that interventions connected by a narrative are more positively greeted by users than a series of unrelated interventions. A further benefit of the application of realistic narrative is noted by Ochs and Capps (2001) who point out that students participating in narrative-led tasks create, via team discussions, their own collaboratively forged, oral narratives to explain, make sense of, and solve the problems before them. What might be called ‘talking it through’.

Schank and Abelson (1995: 1-85) go so far as to say that virtually all human knowledge is represented in terms of stories. They write, “It is hard to remember abstractions unanchored in specific experiences, but it is relatively easy to remember a good story”. Brewer (1995: 109-120), however, believes that they are almost certainly exaggerating in making this claim. Bearman (1997) in discussing this criticism by Brewer, says that, “while there is certainly some dispute as to the more controversial claims that *all* knowledge and memory is framed by stories, there is no question that narrative is important to human beings.”

The utilisation of narrative within a teaching context also appears to help with cognition and the connecting of freshly received information to existing stored knowledge and personal experiences. The ability of narrative to assist with building schemata in this way seems to be because, as suggested by Caine and Caine (2005), the organisation of information into a narrative form is a natural formatting process for the brain. It may also make learning easier as it appears that narratives, by placing some context and 'reality' around the material, provide a more natural way of learning than the usual engineering course delivery methods of lectures, conventionally formatted PowerPoint presentations and topic specific handouts. Stone (2003) maintains that, "People primarily think narratively rather than analytically or argumentatively". Caine and Caine regard stories as metaphors that are intrinsic to the acquisition or construction of new knowledge while Plowman (1996: 92-105) says that, "Narrative should accommodate and unify both the fictional and pedagogical elements so that the tasks are integral to the narrative".

As an example of the power of narrative to aid memory and learning, this researcher can still recall a compelling story told in his first undergraduate year by a lecturer in metallurgy. The story was about the flooding and damage in the lecturer's relatively new home caused by corrosion in water pipes fitted with valves and unions of dissimilar metal. Thus, the causes and mechanisms of de-zincification corrosion can still be remembered in great detail because of the image of the flooded house that resulted and the sympathy of the class for his plight. In contrast, most of the detail of contemporary material presented by other lecturers has long since faded. It appears that the reason that this lecture was remembered so clearly was that it was a story; a coherent account of a believable and comprehensible event, within a recognisable personal frame of reference (most people have experienced a flood at home of some kind) and that had a relevant lesson for the audience (don't mix brass and steel components in fluid systems!). The story produced clear visual images in the mind that were memorable and therefore an effective way of both gaining, and being able to retrieve, knowledge. This experience supports both Schacter (1996), who points out that information will be remembered more effectively when it is encoded in such images or constructed narrative in memory for later recall, and MacDaniel (2004) who writes that stories are vessels for storing and communicating complex ideas and can be very efficient in helping to learn unfamiliar

material. Abrahamson (1998: 12) also astutely describes this sort of experience, “The teller and the listener come together on a cognitive and emotional level that allows the listener to relate to the teller from his or her own personal framework and thus grasp the teller's perception of the content at the same time. This represents a remarkable, and yet very common, interpersonal experience”.

LeBlanc and Hogg (2006) offer some words of caution from Walter Swap (2001: 99-114) about the use of narrative because, “... artificially constructed stories ultimately will be less effective than true ones”. They go on to say that therefore, “Stories should not be invented simply to teach in a lecture or get across a particular topic. In other words, stories should not be made up to teach a lesson or strategy – they should be real stories from real experiences”. However, Swap’s comment was made in the context of his advice to company managers, when attempting to change their organisation’s culture, to utilise real stories of previous relevant events from within the organisation (of which there should be many) rather than make them up.

Denning (2001) goes further and says that storytelling can actually be counter-productive when the story told is not true. In this researcher’s view, provided that the narrative is well supported by corroborative detail and is believable and consistent, a fictional enterprise can be effective in improving course delivery in ill-defined domains.

Graesser and Ottati (1995: 121-132) have published empirical studies clearly showing the vital role that narrative plays in the comprehension, remembering, recall and organisation of events. Bearman (1997) similarly, ends her discussion on narratives and case-based teaching methods by concluding that, “while there are many unanswered questions and a lack of empirical evidence, narratives can be an important consideration in educational technology design. The psychologists’ case for humankind’s tendency towards understanding through narrative is very compelling.”

As an extension of the use of narrative to set the scene for the proposed intervention, the use of virtual staff for the virtual enterprise is also important. According to Weller (2000) the use of characters ‘humanises’ the topic taught and assists in the creation of a narrative which is intrinsically motivating and interesting to the student, creates momentum for the delivery process and makes the context more authentic.

In summary, it seems clear from the literature that the use of narrative is of benefit in the delivery of educational materials. Narrative assists in the understanding, memorisation and recall of information. In the context of this research the students' encounter with the narrative is expected to assist with meeting the research goals concerned with improving student motivation and engagement with the course material. By acting as a connecting thread it is also expected to assist students to comprehend the various topics in the complex ill-defined domain of manufacturing systems as a coherent and integrated whole.

The intervention which is the subject of this research will employ the tool of narrative in a novel way and more extensively than any of the examples of manufacturing education interventions discovered in the literature. The narrative will be the "chain of events in cause-effect relationship occurring in time and space" (Bizzocchi and Woodbury, 2003: 550-568) which will justify the sequence of the course topics and cement the topics and tasks together.

If the application of narrative to the virtual factory scenario is to be successful the design of the intervention needs to take account of the suggestions and cautions noted from this review of the literature on the topic and they are incorporated into the following design specification:

- The narrative will provide a coherent and logical structure which will allow the course to address a range of topics which might otherwise appear disconnected.
- The narrative scenario will be realistic, comprehensible and valid to establish the bona fides of the virtual enterprise.
- The narrative scenario will be comprehensive enough to be realistic but not so complex as to render the intervention less flexible when used by other practitioners.
- The virtual enterprise will be accompanied by a substantial amount of realia and corroborative detail. In addition the narrator will remain constant in the form of the virtual enterprise's Manufacturing Manager.

2.6.13. Motivation

One of the desired outcomes of this research is an intervention that will increase the levels of student motivation in primarily ill-defined areas of study such as manufacturing systems and engineering management. The purpose of this section of the

literature review is to examine the major theories addressing the issue of what motivates students to learn and the possible influence of the educator upon this motivation. This review is carried out in order to isolate those factors that can be applied, with advantage, to the design of the proposed intervention.

Motivation is an important component in most theories of learning with, as Weiner (1990: 616-622) points out, behavioural theories tending to focus on extrinsic motivation (giving rewards) while cognitive theories are concerned with intrinsic motivation (student goals). Hidi and Harackiewicz (2000: 151-179) maintain that intrinsic and extrinsic motivational influences are not mutually exclusive and that the two can have reinforcing benefits. They believe that extrinsic motivation may be particularly valuable for under-achieving students who tend to lack intrinsic motivation.

There are several classic theories of motivation widely described in the literature resources. These include Maslow's Hierarchy of Needs (1954), McGregor's Theory X and Theory Y (1960), and McClelland's Need for Achievement theory (1984). A useful resource in this field is Eccles' review of the literature on motivation (2002: 109-132).

The Maslow 'Hierarchy of Needs' classifies human motives into five categories: physiological needs; safety needs; social needs; ego needs; self actualisation needs. Each of the needs in the list, first to last, must be satisfied before the next need in the list becomes a motivator. Porter's (1961: 1-10) detailed studies between 1961 and 1963 added endorsement to Maslow's theory, as has recent research by Ronan (2001: 341-368), quoted by Latham and Ernst (2006: 181-198).

McGregor's Theory X and Theory Y is a concept, built around Maslow's 'self-actualisation' need, and which offers two opposing motivational strategies for managers. Theory X postulates that the average person has a dislike of work and will avoid it if they can, desires direction and dislikes responsibility. Therefore, most people must be controlled and threatened before they will work hard enough. Theory Y maintains that expending physical and mental effort in work is a natural part of human nature and, if given the opportunity and suitable encouragement, people will exhibit enthusiasm and creativity in solving workplace problems. Managers adhering to this Theory Y are thought to be better motivators since they provide the opportunity for staff to fulfil

themselves and that this opportunity, for self-control and self-direction, promotes higher levels of motivation.

Although Maslow and McGregor's theories are still relevant in the workplace environment, and remain fixtures in university courses in business and engineering management, there is scant evidence in the literature of their planned application to education to assist student performance. For the typical New Zealand university student the most relevant items in Maslow's needs hierarchy would seem to be the higher levels of ego and self-actualisation needs. These are addressed generally in education by the awarding of grades for work done and useful feedback on student performance.

Consideration also needs to be taken of the influence of lecturers upon student motivation. Markwell (2004: 323-325), referring to McGregor's theory of motivation, believes that lecturers bring a Theory X or Theory Y bias with them into the lecture theatre and that, "this bias is perceived by the students and has a profound impact on the students' motivation and eventual success." A lecturer can be defined as having a Theory X bias, says Markwell, if they believe that students have little motivation to learn new material and require the lecturer to act as the source of all information and actively transmit it to the students. On the other hand a lecturer is thought to have a Theory Y bias if they assume that learning is as natural to students as rest or play, that the self-satisfaction obtained from learning is enough to motivate students to achieving the educational objectives, and that students will accept responsibility for their own learning. In reality, of course, few lecturers would be pure Theory X or Theory Y, and many students will successfully complete the course material regardless of the lecturer's orientation. Practitioners implementing this study's proposed intervention, by accepting a challenge, may be supposed to be Theory Y types rather than Theory X!

McClelland's Need for Achievement theory (1984) postulates that individuals possess needs that motivate them to adopt behaviour which will assist in the satisfaction of that need. These needs are shaped by one's environment and previous experiences and most can be classified as a need for achievement, or affiliation, or power. Following research over a period of time at Harvard University, McClelland postulated that achievers like to take responsibility for solving problems, like feedback on how they are performing and prefer to undertake *moderately* difficult tasks. That is, tasks that are not simple (which

anyone could do) or very difficult (where success may depend more on luck than ability). Achievers like to work alone or with other high achievers. On the other hand, individuals with a need for affiliation seek interaction with, and acceptance by, the work group and harmonious relationships with others. Individuals with a need for power may seek personal power – direction of others, or institutional power – by organising others to meet their team's or organisation's goals. Engineering educators observe examples of this behaviour often in the lecture theatre and tutorial classes and it is perhaps even more pronounced in team-based activities. However, it is difficult to see how manipulating these needs to improve motivation could be carried out in everyday practice. For example, it is conventional practice to compose teams with students of varying abilities rather than placing high achievers with other high achievers, and so on.

Keller (1983: 383-429), however, suggested an instructional design model for motivation in education that was not reliant on innate proclivities. His model included four factors for motivation: arousing interest; creating relevance; developing the expectation of success; and producing satisfaction through intrinsic and extrinsic rewards.

Following the same line of investigation, Schiefele (1991: 299 - 323) has shown that interest, in addition to providing emotional satisfaction to the learner, can directly affect cognitive functioning, leading to benefits in enhanced learning outcomes as a consequence of better retention of material in long-term memory. Some researchers on motivation (Hidi and Anderson, 1992: 215 - 238) have differentiated between an individual's personal, innate proclivities with respect to an interest, action or activity and the appeal of an action or activity based upon the way it is presented, i.e. its situational interest.

Bruner (1960) also believes that the best stimulus to learning is interest in the material rather than external rewards such as grades, although in the experience of the researcher that this is not always the case, for engineering undergraduates at least. Mitchell (1993: 424-436), believes that when engaging in a task which is situationally interesting to the student he, or she, is likely to improve their performance. Further, Hidi and Berndorff (1998: 249-446), also believe that situational interest has a higher potential for motivation than innate individual interest because the teacher can manipulate, or vary,

the design of the learning task to suit. Studies by Chen and Darst (2001: 383-400) have shown that a task should include a high cognitive demand in order to achieve high situational interest. Students of course have widely differing interests and lecturers have little time to discover how well an individual student's interests align with the course content. It is difficult therefore to plan and apply different teaching strategies to make the best use of a student's existing interests in the delivery of the course topics.

Situational interest however, can be manipulated by the lecturer to his or her advantage to assist the students to more actively engage with the activity. When considering the students in a manufacturing systems, or similar, course, motivation may be a product of a student's self-belief in their likely success in the topic, i.e. a good grade. People are more interested and motivated by tasks in which they expect to do well, whether it be completing crosswords or playing tennis. Also the perceived relevance of the material to future careers may be a further motivator.

The proposed intervention will be designed to address the issue of motivation (a component of research question 2) by applying the motivational driver most easily manipulated – situational interest in the design of the intervention and will incorporate Keller's four factors. This will be achieved primarily by the creation of a complex and believable narrative which will form an authentic setting for topic delivery.

2.6.14. Student Approaches to learning

This section will review the literature concerning various student approaches to learning and seek to identify those factors which, if incorporated into the design of the proposed intervention, will assist in achieving the desired, improved, learning outcomes.

Associated with the topic of individual student learning styles, discussed in Section 2.7.15, is the concept of individual student approaches to learning. Original work by Marton and Säljö (1976: 115-127), followed by supplementary research from Van Rossum and Schenk (1984: 73-83), quoted by Good and Brophy (1990), and work by Biggs (1987) and Ramsden (2003), led to the theory that students could adopt various strategies in their attempts to come to grips with the material being taught. They could adopt either a 'surface' or a 'deep' approach to learning. This theory is widely discussed in the educational literature in the context of tertiary education and Houghton (2004) writes that the concept is particularly worth consideration by engineering educators who

need to concentrate not only on the key concepts in isolation, but demonstrate the way that components link together. He says that, “over reliance on traditional lectures, where students are passively taking notes and not being required to engage actively with material, will not encourage a deep approach. Similarly, over assessment through repeated testing, while seeming to focus the learners on the material, is likely to have the opposite effect to that desired by just encouraging memorising of facts”.

Students with a surface approach to learning emphasise in their study the remembrance of isolated facts with a view to being able to answer later examination or test questions. They limit their investigations only to what is required to be known and, additionally, may well have a negative view of their learning experience at university. Students with a deep approach, on the other hand, attempt to grasp the totality of the concepts being covered and seek to integrate new information with what they already know about the topic. This learning approach helps the student to better apply new information to solve problems in new and differing contexts. Deep learning students may also seek to acquire more information about the subject beyond the course requirements and possess a positive attitude to their university studies.

A review of the literature on the subject of student approaches to learning and student motivation shows that the great majority of publications indicate that a deep approach to learning correlates with intrinsic motivation whilst surface approaches correlate with extrinsic motivation (Lyke and Kelaher-Young, 2006: 477-490, West-Burnham, 2006: 33-47, Young, 2005: 25-40). This may be true in the general case, however, one can visualise occasions when the ‘deep-intrinsic’, surface-extrinsic’ dyad association may differ. For example, one might be curious to know how one’s refrigerator keeps food cold and find out what one can about it from friend, magazines and books. The effort (surface learning) is simply to satisfy one’s curiosity (intrinsic motivation) and is concentrated on one issue and does not lead to learning about the science of thermodynamics. Conversely, a new parent could research the literature in child psychology quite deeply in order to assist in parenting a child. Such knowledge would presumably bring extrinsic rewards in the form of a contented child.

Before examining how engineering student approaches to learning may be influenced by this research and the proposed intervention, it would be instructive to know what

students themselves believe what 'learning' is. Following a study utilising interviews with students, with a wide range of ages and educational backgrounds, Säljö (1979) sorted the various concepts of learning held by students into five general classes:

1. Learning is a quantitative increase in knowledge. Learning is acquiring information or 'knowing a lot'.
2. Learning is memorising. Learning is storing information that can be reproduced.
3. Learning is acquiring facts, skills and methods that can be retained and used as necessary.
4. Learning is making sense or abstracting meaning. Learning involves relating parts of the subject matter to others and to the real world.
5. Learning is interpreting and understanding reality in a different way, comprehending the world by re-interpreting knowledge.

Students subscribing to one of the first three classifications would be described as primarily surface learners whilst students who believed learning was best described by classifications four or five would be classed as primarily deep learners. Although Säljö's research did not specifically target those studying engineering, it seems reasonable to believe that these varying conceptions of what 'learning' is would be present in any cohort of engineering undergraduates.

It is important to note that, according to Ramsden (2003), the learning approach of a student is not a fixed characteristic and a student may use both approaches at different times, although they may have a bias towards one or the other. Experience indicates that students, in fact, often seem to position themselves along a continuum between the extremes of the two approaches depending upon the circumstances at the time.

Entwistle and Ramsden (1983) have suggested that there is a third strategy utilised by some students, a sophisticated adaptation of surface learning – the 'strategic' approach. Students adopting this technique have the goal of achieving the highest grade possible by managing their study time, focusing effectively, and carrying out a thorough analysis of the course assessment requirements. It may well be that this approach is more typical of students' learning methods than either of the simple opposites of 'surface' or 'deep' perspectives. Unlike the research data revealing surface/deep learning which was gathered from students reading a fixed text in an experimental environment, the

‘strategic’ approach was discovered by observing students in their everyday study activities (Entwistle and Ramsden, 1983). Their natural habitat as it were.

Thus, if their approach to learning is not a fixed characteristic, the question arises; how can we motivate students to choose the most suitable approach? Note that the general tone of the published research assumes that deep learning is the best strategy for learners to undertake. One can envision, however, circumstances where a surface approach may have the most utility for the student and be adopted consciously. For example, if an examination is expected to require the recall of facts contained in the lectures and course texts, the best strategy for the student may be to take detailed notes in the lectures, assess which topics are most likely to be assessed and attempt to memorise the notes and text in cramming just prior to the examination.

The factors that might encourage surface learning, Kember and Gow (1989: 263-288) believe, include: lack of interest in the material; a heavy workload; recall-type of assessment methods; a lack of interest by lecturers; and motivation which is extrinsically driven. Addressing these factors will reduce the inclination of students to adopt a surface learning strategy.

Biggs (2007) suggests that deep approaches to learning can be fostered by clearly stating the aims of the course and by making connections between different course topics and with material that the students have learnt in previous years. Also useful is relating authentic course content to the workplace, teamwork and interaction, a focus on understanding the concepts rather than raw facts and utilising authentic assessment tasks that require some engagement by students.

When teaching, engineering practitioners need to recognise that, although cognitive process is important for deep learning, the foundation theory of the topic cannot be neglected. For example, although the ability to design, implement and maintain a quality assurance system within a manufacturing organisation requires synthesis and analysis skills it also requires a good understanding of basic statistics and, for example, the characteristics of the Normal distribution.

Ramsden (1981: 368-383) and Nelson et al. (2005) found that, in general, students in domains such as the arts, humanities and social sciences were more likely to utilise deep approaches to learning than students in engineering and the sciences. Nelson et al. quote

Felder and Brent's criticism of engineering education (2005: 57-72), "A single approach has dominated engineering education since its inception: the professor lectures and the students attempt to absorb the lecture content and reproduce it in examinations. That particular size fits almost nobody: it violates virtually every principle of effective instruction established by modern cognitive science and educational psychology". The proposed intervention, by presenting an immersive, authentic context for learning, will provide the conditions necessary to promote deep learning approaches from students.

There is evidence in the literature of a positive correlation between deep learning approaches, either alone or combined with a strategic approach, and improved results in summative assessments (Taylor and Hyde, 2000, Watkins, 2001: 165-195, Zeegers, 2001: 115-132). Diseth (2003) and Diseth and Martinsen (2003: 195-207), consistently found that the surface approach to learning correlates negatively with academic success. In their studies of 119 first-year education psychology students Burton and Nelson (2006) found that grade point average was negatively correlated with the surface learning approach ($r = -0.23$, $p < 0.05$) and was also significantly positively correlated with both deep and strategic learning approaches ($r=3.99$, $p < 0.05$). They suggest that, "a deep approach may be more likely to predict academic success in the latter years of a degree, when assessment procedures directly reward a demonstration of conceptual understanding". Groves, however, following her investigations with first-year medical students (2005: 315 - 326) states that, "No correlation was found between learning approach and examination results". This disparity in conclusions may be because learning approaches appear to be strongly context sensitive, as discussed above, and because of differences in the particulars of the summative assessment instruments applied.

Intuitively, it would be expected that this increase in academic performance (as reported by Zeegers and others) as a result of adopting a primarily deep learning strategy would also be reflected in subsequent performance in the workplace. However, although many companies report successful implementation of 'deep learning' strategies in company training programmes, there seems to be no existing research reporting on the relative performance of deep versus surface learners following graduation.

In research work published by Lizzio et al. (2002: 27-52) students report that the learning environments that will most strongly influence them towards deeper processing are those, “which are within an intrinsically motivating context (work to make subjects interesting and motivate students to do their best work)”.

In designing the proposed intervention to encourage a deep approach to learning, the factors that Biggs says are important in influencing a student’s approach to learning will be addressed, i.e. assessment, syllabus and teaching. Ramsden (2003), however, warns that over-enthusiastic efforts by teachers to convey to students that they should engage in deep learning tend to only succeed in making surface learners attempt to imitate a deep approach by carrying out more complex efforts to contextualise material from a surface basis.

2.7. Accommodating Learners

2.7.15. Learning Styles

For many decades research has been carried out by educationalists and psychologists to attempt to categorise and understand the various approaches that individuals have to learning, understanding, and the retention of new ideas and information. These individualistic techniques have been variously described as learning styles, cognitive styles or field dependent learning.

Riding and Cheema (1991: 193-215) examined the terminology surrounding learning styles and write that ‘learning style’ seems to have emerged as a more common term as a replacement for the term ‘cognitive style’ in the 1970’s. The impression, they say, is formed that “those working in the field who use the term ‘learning style’, do take cognitive styles into consideration, but would probably describe themselves as more interested in practical, educational or training applications and are ‘action-orientated’, whilst the term ‘cognitive style’ has been reserved for use with more theoretical and academic analysis and description”. Das (1988), for example, considers the two to be different and attempts to define them as separate concepts. However, Riding and Cheema also point out that some researchers, e.g. Entwistle (1981) have used the terms interchangeably.

Keefe and Ferrell (1990: 57-61) describe learning styles as the “cognitive, affective, and physiological traits that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment”. Gregorc (1979: 234-237), quoted by Coffield et al. (2004), describes them as “distinctive behaviours which serve as indicators of how a person learns from, and adapts to, his environment”. Kolb’s (1984) definition of learning styles allows for changes in style according to circumstance and says that, “learning styles represent preferences for one mode of adaptation over another but these preferences do not operate to the exclusion of other adaptive modes and will vary from time to time and situation to situation”.

Riding and Douglas believe that designing teaching interventions to suit various learning styles is of benefit to students (1993: 297-307). Whilst, with respect to students’ intellectual development, Felder says (2004: 289) “A necessary condition for a student’s intellectual growth is challenge to the beliefs that characterise his or her current level. Students who believe that all knowledge is certain and all problems have solutions must be challenged with issues that cannot be neatly resolved and open-ended problems that have many possible acceptable solutions”.

In a later publication Felder and Brent (2005: 57-72) write that the more clearly educators understand the differences between students in their attitudes to learning and their responses to different classroom environments and instructional methods, the more likely they are to meet their students’ differing learning needs. There are three categories within student cohorts, they say, the diversity of which have implications for teaching and learning. These categories are differences in students’ learning styles, approaches to learning (surface, deep, or strategic), and levels of intellectual development. Teachers who are aware of their students’ learning styles, and their own, can make better pedagogical decisions in the design and delivery of their courses according to Hawk and Shaw (2007: 1-19). Pilay (1998: 171-182) also believes that learning styles are an important consideration in designing and delivering instruction.

A number of theories have been proposed as a means to provide a both a descriptive structure and a rationale for the individually distinctive behaviours defined in the previous paragraphs. Chief amongst these are Kolb’s learning styles which are derived from his experiential learning cycle (1981: 232-305); Witkin’s et al. (1977: 1-64), Field-

Dependent and Field-Independent styles; Cognitive Style Differences as proposed and described by Gregorc (1979: 234-237); Gardener's Theory of Multiple Intelligences (1993) and Felder and Silverman's Index of Learning Styles (LSI) (1995: 21-31). A review of the literature reveals that the two most researched learning style assessment instruments appear to be the Kolb learning Style Inventory and the Felder-Solomon Inventory of Learning Styles.

Kolb (1984) believed that many students seemed disadvantaged as a result of their learning styles not matching the discipline they were studying. Also, according to Jensen and Wood (2000), identifying students' learning styles in order to build teams based upon a complementary mixture of styles has had very positive results leading to improved team effectiveness, leadership, creativity and problem solving abilities.

Curry (1990: 50-56) disagrees with this stance and has questioned the value of attempting to study the characteristics of learning styles, and of the usefulness of their application to learning design. She argues that there are three general problems with their use. These are: firstly, the variety and number of definitions of what a learning style actually is; secondly, the weakness in empirical evidence for the reliability and validity of learning style measuring procedures and instruments; thirdly, the lack of a clear view of which kinds of changes to teaching practice would be beneficial for which types of learning styles. As evidence to support her misgivings about the third issue, Curry notes that, overall, researchers in the field are not agreed as to whether, or not, better results are achieved for learners when teaching methods and learning styles are matched or deliberately mismatched. As evidence of this split she quotes the work of Witkin et al. (1977: 1-64) who suggested that, "matching students with teachers or instructional materials according to their cognitive styles might facilitate the students' initial acquisition of skills and provide important continued motivation" and contrasts this with the opinions of Shipman and Shipman (1985) who suggest, "In a complex changing society with diverse environmental demands, students need the opportunity to become sensitive to, and proficient in, multiple alternative strategies". Additionally, she quotes Snow and Lohman (1984: 347-376) who cover both bases by suggesting, "matching student style to instructional format for the initial stages of learning, and then moving to systematic mismatches as the student becomes more proficient with the material".

Kirby (1988: 229-274) however, disagrees with Witkin et al. and argues that, “the best learning style for understanding instruction is the absence of any identified style or even any style-like consistency in approach”. Kirby advocates that learners take a very flexible approach to instruction, one that can be easily modified as more cues become available about the learning conditions and Kirby refers to this flexibility as a ‘synthetic style’. Kolb (1984) concedes that learning styles are ‘flexibly stable’ and may change slightly from situation to situation. Nulty and Barrett (1986: 333-345) found that students in the first third of their studies adopted learning styles that were similar to each other irrespective of their main disciplines. However, the learning styles of students in the final third of their studies tended to be related to the discipline that was the primary focus of their studies.

Kolb claims that there is a relationship between academic specialisation and learning styles. So, students studying management may be expected to, in general, prefer an accommodative (characteristic question – ‘what if?’) learning style whilst engineering falls into the category of active experimentation so its students will be primarily convergers (characteristic question – ‘how?’). “People chose fields that are consistent with their learning styles and are further shaped to fit the learning norms of their field once they are in it.” (Kolb, 1984).

Despite the fact that many psychologists do not endorse the concept of learning styles, as Montgomery points out (2001: 1-8), the notion of such styles, “resonates amongst faculty and students” and he believes that an understanding of such styles can have a positive impact on the teaching methods of all teaching staff.

The voluminous amount of publications on the topic of learning styles encountered in the literature review indicates that the concept of a preferred learning style within individuals is an intriguing one for both researchers in education and for practitioners.

2.7.16. Theories of Intellectual Development

The domain of manufacturing systems, for which the proposed intervention is to be designed, is generally regarded as an ill-defined one (Chen and Wu, 2008: 53-60, Hadavi et al., 1992, Steiner, 2004). It is so defined because there is, generally, no one systematic method or procedure to determine whether, or not, a proposed solution to a manufacturing system problem is an optimum one. The most common reason for this is

because the parameters defining manufacturing problems are numerous, have poorly understood relationships between them and may be subject to substantial variation in the values they adopt.

As a result of this characteristic, one of the answers sought in this research study is how can students studying ill-defined courses be better equipped to deal with problems? Students are to be assisted to accept that many problems they may encounter as professional engineers have many valid answers, and, in fact, it may not be possible to determine which of the answers is the best or optimum one.

Additionally, if the proposed intervention is to meet its objective of improving the delivery of the manufacturing systems course for all students, then the design must seek to be fully inclusive regardless of each student's personal epistemological position.

This section of the literature review will examine the research on learners' possible epistemological stances and review the methods by which students' levels of intellectual development may be measured. The purpose of this is to ensure that, within the limits of the evaluation instrument used, the level of indeterminacy in the problems presented to students is not disjoint with the students' intellectual readiness to attempt them.

A review of the literature reveals that there are four major theories of intellectual, epistemological, or cognitive, development:

- Perry's Model of Intellectual Development (Perry, 1981).
- The King-Kitchener Model of Reflective Judgment (King and Kitchener, 1994).
- Baxter Magolda's Model of Epistemological Development (Baxter Magolda, 2001).
- Belenky et al. - Women's Ways of Knowing (Belenky et al., 1986).

The King-Kitchener Model of Reflective Judgment (King and Kitchener, 1994) is a widely used scheme outside the field of engineering education. The low and intermediate positions of the King-Kitchener and Perry models are a close match. They match less well at the higher levels. Baxter Magolda's Model of Epistemological Development (Baxter Magolda, 2001) integrates the Perry, King-Kitchener and Belenky models by describing alternative patterns for all but the highest positions.

Of the four theories Perry's model has been explored and utilised most widely in education (Culver and Hackos, 1982: 221-226, Pavelich and Moore, 1993: 451-455, Wise et al., 2004: 103-110).

Perry's original study can be criticised on the grounds that his student sample was a fairly homogenous group; almost exclusively male, of a similar age and culture and from relatively affluent backgrounds. Belenky addressed the issue of gender (1986) with a series of interviews and has shown that some modification, and an alternative progression of stages, is required for Perry's model, if it is to be applied to the intellectual development of women.

A number of researchers have worked on the application and development of Perry's model in engineering including Culver and Hackos (1982: 221-226) and Marra et al. (2000: 39-46). These later researchers suggested that the effort required by students to define open-ended or ill-defined problems and specify their assumptions would facilitate their intellectual growth. Irish (1999: 83-100) utilised Perry's Scheme of Intellectual Development to inform the design of writing assignments in engineering in order to enhance the role of writing as a mode of learning.

Later studies by Moore (1989: 504-514) have generally confirmed the results obtained by Perry in his initial investigations at Harvard University. Of course, the model has not gone unchallenged. Bizzell, for example (1984: 447-454), charges that Perry's model is inherently value-laden insofar as it assumes that relativism (the ability to think critically or reflectively) is the most desirable intellectual stance and is perhaps an end in itself.

2.7.16.1. Perry's model of intellectual development

Briefly, Perry's model (1970) is that maturing students move intellectually from a dualistic, black and white, or right versus wrong view of the world, to a relativistic view which allows for uncertainty and shades of grey. The importance of studies such as Perry's for engineering educators is that it posits that students will not be able to understand, or answer, open-ended problems which require a stage of intellectual development beyond that which they currently possess.

Perry suggested that students move through a number of positions in reaching intellectual maturity. Position 1 (Basic Duality) may be described as one where the student believes that the teacher knows all the answers and his, or her, job is to teach

them to the students. In position 2 (Dualism or Multiplicity Pre-legitimate) the student will allow that some shades of grey (Multiplicity) may exist but still believes in only one answer to problems. Alternative solutions are either wrong or simply the result of the teacher throwing up a smoke screen to make students search for the one 'correct' answer.

At position 3 (Early Multiplicity) the student realises that it is impossible to continue to ignore the possibility of multiple points of view although he, or she, still believes that there is only one answer, it's just that 'they' (the teachers) do not know it, or are uncertain what it is.

At position 4 (Advanced Multiplicity) students come to believe that accepting uncertainty in solutions is a legitimate stance even though they still fundamentally believe that solutions are either right or wrong. Some students realise at this stage that to play the 'grading' game successfully they must make, at least, a pretence of considering alternative solutions if they are to achieve good marks.

Once the student's intellectual development has proceeded onto position 5 (Relativism), and beyond, all issues are seen as relative. The student can now stand outside the problem and think objectively about it. The teacher is not now expected to know all things, but to be able to provide expert help when needed and to guide the student in forming likely solutions.

Positions 6 through to position 9 see a maturing of this relativistic stance and an increasing level of commitment to choices made in learning and in life. These are advanced levels of development, which may not be reached by all mature adults.

Perry noted that intellectual development could occur rapidly or slowly through the different positions and that students may choose to 'temporise', 'retreat' or 'escape'.

Temporising is a pause in the process of growth which may simply be a time for consolidation and to 'take a breath' or it may be the precursor to retreat or escape.

Retreat is a movement back to earlier positions when the concepts of relativism and multiplicity become overwhelming for the student. In adopting an escape strategy the student avoids an awkward commitment stance by exploiting the move towards detachment contained within positions 4 and 5. Wankat and Oreovicz (1993: 277), describe two paths of escape noted by Perry:

“In ‘dissociation’ the student drifts into a passive delegation of responsibility to fate. He, or she, settles in position 4. The alternate path is ‘encapsulation’, which may be a favourite of engineering students. In encapsulation one avoids relativism by sheer competence in one’s field. The student becomes very good at engineering but avoids any questions of deeper meaning or value. Escape need not be permanent and engineers can use encapsulation to stay in position 4 or 5 for several years”.

It can be noted that the literature indicates that Perry’s position 5 is generally ignored in university intellectual development surveys as it seldom appears in undergraduate students. In any event, beyond position 5 there is a movement in focus from intellectual to moral and ethical development which has proved difficult to assess with the usual objective measurement instruments.

The only classes which may assist students to move from a dualist to a relativist position are those classes which present problems in which multiple answers exist. Unfortunately, even after completion of a course with such problems it is likely that this legitimatisation of multiplicity will not be reinforced by the presence of similar problems in their other courses.

Progressing through the positions, suggest Wankat and Oreoviez (1993: 277), can be encouraged a diversity of learning tasks, concrete experiences such as case studies, teamwork, and encouragement to offer alternative solutions to problems (risk taking).

2.7.16.2. Intellectual Development Measurement

Perry and many later researchers utilised experienced interviewers and trained raters to measure intellectual development levels. The interviewers carried out structured, open-ended interviews and the raters scrutinised the interview transcripts in order to assign the relevant position to the interviewee. Although this is certainly the most reliable method of assessment the process is lengthy and the cost for most research programmes is prohibitive.

To get around this problem some workers have developed pencil-and-paper methods of assessment which are considerably cheaper and easier to apply and to score. For the Perry scheme the instruments are the Measure of Intellectual Development (MID) (Moore, 2000) which requires the respondents to write an essay, and the Learning

Environment Preferences (LEP) questionnaire developed by Moore (2000) which contains 13 statements which the respondents rate on a four-point Likert scale. Olds et al. (2000) report the development of a software package, COGITO, which uses a neural network to find patterns in paper-and-pencil data and relates them to the Perry scale. The authors maintain that early results show a high correlation between results from the software and from interviews.

While pencil-and-paper instruments are easier and faster to administer than interviews, the ratings obtained tend to be lower than ratings obtained with interviews and correlate moderately, at best, with interview ratings (Pavelich and Moore, 1993: 451-455). However in the case of this study, which seeks to improve the capacity for dealing with indeterminate problems for a group of students, an indication of the range of Perry positions in the cohort is all that is required to assist. An accurate assessment of individual students is not required.

2.7.16.3. Perry's positions

Perry's work, as Moore says (2002: 21) “underscores the notion that the most powerful learning, the learning most lecturers really want to see, is a significant qualitative change in the way learners approach their learning and their subject matter”.

In Culver's opinion (1996: 1287-1290) many educators find Perry's description of the developmental journey taken by college students, “to be helpful in defining the growth we seek in our students”. Culver also makes the point, relevant to this research, that text books, as used in almost all engineering courses, with fully defined problems of two or three paragraphs and answers at the end of the chapter, do not encourage growth. They do not enable students to deal with ill-defined problems with multiple answers or encourage the movement from dualistic to relativistic positions. Importantly, for the teacher who must mentor students through material and assignments of an open-ended or indeterminate nature, Perry's research indicates that students will not comprehend, or be able to handle without frustration, problems that are a significant mismatch to their current level of intellectual development (Perry, 1981).

McMahon (2005: 277-281) published a paper on the use of Perry's scheme in the planning of teaching materials and teaching processes. He made no measurements of student positions but made the point that student reactions when they are forced to

confront multiplicity can include anger, resentment and defensiveness and this can lead to students reporting negative comments on the course and the teacher.

As far as typical student positions on Perry's scale are concerned, Felder (2004: 289) quotes Jehng et al. (1993: 23-35) and Paulsen and Wells (1998: 365-384) who show that students in engineering and the sciences are more likely to be dualistic and believe in the certainty of knowledge and of authority than students in the social sciences and humanities who are more likely to take a relativistic and questioning position.

Miller, Pavelich and Olds (1998) report, in their investigation into the intellectual development of students at the Columbia School of Mines, that a few first year students were clearly in position 2 with a fairly large number of students in transition between positions 2 and 3, with a Perry position mean of 2.8 in the sample. Pavelich and Moore investigated (1993: 451-455) science and engineering students at the same institute. They reported a mean Perry position for second year (sophomore) students of 3.7 and for seniors, 4.5. Two-thirds of students did not reach position 5 before graduating. According to Wankat and Oreovicz (1993: 277) this transition region appears to be the minimum level at which a student can successfully study and practice engineering. Even so, students at this level of development cannot see the big picture, and without further intellectual growth, they are unlikely to advance significantly in their engineering careers. Fitch and Culver (1984: 712-717) observed no undergraduate engineering students in position 4 or higher.

Palmer et al. (2000) also carried out a longitudinal assessment programme of engineering students positions on Perry's scale. Their results for 32 students in year three of their degree showed that the modal position was position 3 and the average was 3.38.

Wise et al. (2004: 103-110) investigated the influence of gender on Perry positions and, unlike Belenky (1986) could not discover a significant effect in their studies on undergraduate engineering students. It seems likely that this is due to the fact that men and women who have self-selected to study engineering have a greater commonality of intellectual position than men and women in the general population. The investigation into students' positions on the Perry scale in this research study will not attempt to discriminate between male and female students. This is as a result of Wise's findings

and because results from the small sample size of female students could not be taken with confidence to be representative.

Engineering students need to adopt a contextualist view of engineering problems if they are to be able to attempt typically complex engineering problems. The indeterminacy of the tasks to be completed in the proposed intervention will encourage them to see that multiple solutions are possible and that they need to be able to identify the criteria to be used to evaluate the solutions open to them.

The proposed intervention will attempt to utilise Perry's model as a viewpoint from which to improve students' ability to solve open-ended problems, make judgments, use evidence and evaluate alternatives. The virtual enterprise will present students with realistic, drawn from life, problems which have vague data sets and ambiguous required outcomes and provide an introduction, perhaps a shock one, to real-life manufacturing engineering.

2.8. Ensuring No Duplication of Effort

It was necessary to check that this present research study does not repeat any previous research so that its results and conclusions will offer a new insight to the delivery of engineering courses in ill-defined domains and the computer-based tools that can assist.

No examples were found in the literature of courses in ill-defined engineering domains which attempted to address some of the pedagogical problems that these courses typically encounter by providing a teaching intervention based upon a valid pedagogical situated learning framework and a comprehensive virtual factory scenario to provide authentic content and context.

Further, no examples of design-based research applied to generating new initiatives in the field of manufacturing engineering could be found in the literature although an example of design-based research in the field of undergraduate science is described by Thompson et al. (Thompson et al., 2004). These researchers claim that the methodology has enabled them to undertake a substantial change in the curriculum in a group of related engineering, mathematical and science courses and had brought an increased understanding of the way in which students develop complex, cross-discipline competencies over several years.

2.9. Summary

This literature review has examined the publications extant in a number of relevant areas and summaries of the findings have been given in the appropriate places in the preceding review. The following is a brief summary of the major findings from the review as they will be used to elicit answers to the research questions and inform the design and development of the proposed computer-based multimedia teaching intervention.

The areas covered have included: (a) the major philosophical theories of learning; (b) past and recent applications of technology applied to education; (c) pedagogical models of instruction and factors influencing student learning including narrative, motivation and deep/shallow approaches to learning; (d) student learning styles and levels of intellectual development.

2.9.17. Theories of Learning:

Three distinct views of the process of learning were reviewed — behavioural, cognitive and constructivist. Each theory describing different levels of cognitive sophistication required by the learner. Ertmer and Newby (Ertmer and Newby, 1993: 50-70) suggest that the most appropriate theory to advance students at a particular level should be adopted, and Smith and Ragan (Smith and Ragan, 2005) say that no single pedagogical theory provides complete prescriptive principles for the whole process of the design of instruction. Ertmer and Newby also, in regards to the design of learning interventions, quote Snelbecker (Snelbecker, 1989: 321-337) as emphasising that designers cannot afford the, “luxury of restricting themselves to only one theoretical position... [They should] select those principles and conceptions which seem to be of value for any particular educational situation”.

A behaviourist, cognitive, constructivist continuum will be adopted for this intervention design in recognition of the fact that students will progress from having no prior knowledge of a topic on to its analysis and later its synthesis. The focus of instruction will be required to move from the transfer of facts and laws (facilitated by a behaviourist approach) to information processing and solving problems with known facts (facilitated by cognitive methods) and then on to the solving of indeterminate problems using heuristic methods (facilitated by a constructivist approach). Although

many constructivists maintain that knowledge about a domain cannot be split up in such an hierarchical fashion (Bednar et al., 1995: 100-111), Jonassen argues that, although constructivist learning approaches are useful for advanced knowledge development, more objective approaches such as behaviourism and cognitivism are useful for obtaining mastery of content and skills in well-defined problem solving. He suggests a move to constructivism as the learner becomes more familiar with the topic and its concepts and obtains the ability to deal with ill-structured and indeterminate problems. The learning experience for students using the planned intervention will first involve the introduction of the topic and an explanation of its relevance and connection to other topics after which the ‘nuts and bolts’ of the topic will be explained including any relevant laws and theory. For example, for the topic of plant layout in the manufacturing systems course, it will be explained why an efficient plant layout is important and how this layout is related to the product, required production rate and the skill levels of available labour. It will be explained that decisions on the layout will have a substantial knock-on effect later on production rates and efficiency. Following this, the formal systematic techniques used in industry to produce an efficient layout are described after which the students will work through sample problems of the process and be shown typical real-life layouts. Finally they will undertake a layout task for the virtual enterprise with the assistance of its virtual staff. This process, to be repeated in a similar manner for the other topics, involves learning some basic facts and rules, becoming familiar with the topic, its environment and nomenclature and, finally, being confident of dealing with indeterminate problems.

2.9.18. Computer-based technology applied to engineering education:

From the review of the history of technology use in the classroom it is clear that improvements in educational outcomes are not guaranteed. The failures that were noted appear to be because the technology itself came to be the centre of the intervention rather than being considered as merely a tool to assist cognition. Mayer (Mayer, 2001) remarked, of failed technology implementations, that, “the driving force behind the implementations was the power of the technology rather than an interest in promoting human cognition”. The lesson from this review of the application of technology to education seems clear. To be successful in promoting motivation and engagement the proposed intervention must be learner-centred rather than technology-centred.

The review of the literature reporting upon the application of computer-based teaching interventions in complex ill-defined engineering courses revealed a number of publications describing the use of computer-based multimedia, computer and paper-based games, simulations and simulation games. The examples in the literature range from interventions aimed at clarifying just one manufacturing topic to those that presented, or simulated, a range of manufacturing system activities. Some of the interventions attempted to provide a backdrop scenario within which the modules of the intervention were based and some described the assessment methods used to assess the effects of the intervention on learning and the results. No examples were found, however, of a multi-topic manufacturing system simulation which presented a fully cogent, coherent and believable narrative within which the total intervention was placed, or which attempted to present a logical flow of tasks through the manufacturing production system from start to finish. No examples were found of a wide ranging simulation in which a valid pedagogical framework was reported as having been used and/or a specific research methodology adopted. The multimedia, game and simulation-game interventions designed for educational use with university students do not seem to have high levels of immersion and believability. The technology and screen navigation tasks in the case of multimedia interventions and the turn-and-turn-about process in games prevents the creation of flow and a believable authentic context.

To provide answers to the research questions it will be necessary to develop a computer-based multimedia intervention and apply it within a suitable pedagogical framework—situated learning. The intervention can be viewed as a ‘workbench’ in the ‘lab experiment’ context. It is expected that it will be adaptable for implementation in domains with similar characteristics such as engineering management, operations management and engineering design.

Many of the examples in the literature utilise multimedia in the form of a local Intranet web site to present to students the problems to be addressed and the background learning material. This ‘inconsistent’ delivery method cannot, inherently, meet the requirement of providing believable authentic context. The level of immersion of the proposed virtual enterprise intervention will be increased if the web site for the designed intervention is designed to do only what commercial websites do. That is, provide information to potential customers about the company, its products, services and

personal contacts. Information which would not be normally available via the Internet such as specifications, process sheets, customer orders and problems for investigation will be sourced as they would be in the workplace, i.e. transmitted by paper e-mail or e-mail attachment and not from a screen in a multimedia presentation.

2.9.19. Pedagogical models and other factors

Gagné (1970) places importance on specifying a hierarchy of tasks whenever a problem solving task can be broken-down into pre-requisite and simpler capabilities. Gagné's conditions of learning theory, as quoted by Kearsley (1994), also specifies a sequence of nine instructional events and their corresponding cognitive processes. These events as supplemented by Gunter and Kenny with simulation analogues will form a part of a template for the intervention's development.

Blooms taxonomy will be adopted as it forms a sound basis for systematically planning and setting the learning objectives to improve topic preparation and delivery.

The intervention will incorporate elements of two important pedagogical theories; Bandura's Social Learning Theory (1977) and Vygotsky's (1978) Zone of Proximal Development (ZPD) by the use of teams in which students will have the opportunity to discuss and negotiate solutions and share expertise with the addition of support from the virtual staff of the enterprise and the lecturer. The learning tasks should provide a reasonable challenge to the students based upon their current knowledge but not so challenging as to discourage achievement. This approach puts responsibility upon the practitioner to provide a coherent and adequate level of scaffolding or support for the learner. Vygotsky pointed out that instruction is best when it proceeds slightly ahead of the student's current level of competence.

The work of Bandura and Vygotsky was an antecedent to situated learning which is the framework adopted for the design of the intervention. Situated learning was adopted because of its potential to improve student levels of motivation and engagement as a result of its emphasis on providing an authentic context, within which ill-defined courses could be presented, and the authentic content of the tasks required. This authenticity requires the creation of a comprehensive virtual enterprise scenario which will provide a means for demonstrating the integrated nature of the topics within the domain and the way in which indeterminate problems can be framed and justified.

Student motivation will also be fostered by clearly stating the aims of the course (Biggs, 2007) and ensuring that connections are made between various course topics and relating content to practical problems in the workplace. Levels of engagement will be increased by providing interactive course tasks that are purposeful and not just 'end-of-the-chapter' exercises. The use of appropriate and relevant video clips showing engineers in action and contact with the staff at the virtual enterprise will also encourage engagement with the topics

The review showed that the literature is sympathetic with the use of narrative to increase levels of motivation and engagement.

The proposed intervention will be a narrative-led, virtual macro-model. The emphasis will be on creating a comprehensive, detailed and coherent narrative which will form the environment within which the virtual enterprise will exist and operate as a working manufacturing system. The virtual enterprise can be termed a virtual macro-model.

Virtual as, although it will contain software elements and paper documentation, it will exist primarily as a virtual organisation in the minds of the students and, importantly, in the same form in the mind of the practitioner. Thus each student's concept of the model will be slightly different. It is termed macro-model because it contains a number of other sub-models within it concerned with individual manufacturing system operations.

To meet the goals of improving the delivery of the manufacturing systems course and increasing student levels of engagement, motivation and awareness of the integrated nature of manufacturing systems, the intervention macro-model must occur over a relatively long-term. In this case, for most of a 12 week course containing 36 lectures and a number of tutorial sessions. It is believed that a longer term of contact with a comprehensive and coherent scenario will be more likely increase engagement whilst including multiple, well connected, topics will effectively demonstrate manufacturing systems integration.

The virtual macro-model is static, only coming to life when imagined and operated on cognitively by the student. The intervention will be realistic enough to make students believe that they are encountering a representation of reality.

It could be argued that the device of a narrative or story is in conflict with the constructivist approach adopted for the 'task' sections of the intervention as it constrains

the student to a particular point of view of the environment. However the tasks will wherever possible encourage the student to take multiple perspectives of the issues from within the narrative scenario, a common device in film narrative for example. Also, as Bearman points out (Bearman, 1997), Bruner argued that stories are inherently interpretive rather than prescriptive (Bruner, 1996).

The aim of the proposed intervention for the manufacturing systems course will be to persuade students to undertake a willing suspension of disbelief and accept the fiction that they are contractors to a virtual enterprise. This suspension of disbelief will be facilitated by means of a unique level of attention to detail, to avoid inconsistencies, and a coherent narrative supplemented with authentic realia. This detailed scenario will make it possible for the students to accept the role that the intervention offers them – that they are working on real problems for a real company within which it is possible for their solutions to be adopted, by the organisation. Thus making their efforts and results important and worthwhile, and their decisions a serious matter not to be undertaken lightly. The goal is to make the intervention realistic enough to make students believe that they are encountering an accurate representation of reality and provide a ‘cognitive realism’ which is the degree to which simulation promotes cognitive activities that are similar to those engaged in by manufacturing systems practitioners.

Communications between the virtual enterprise and students will be carried out in such a way as to mimic as closely as possible the way that communications are carried out in the workplace. That is, by a mixture of e-mails, e-memoranda, paper documents and data on web site pages. The intervention will include a wide range of typical manufacturing company activities from initial workshop layout, through to testing models and simulations of production activities, to scheduling customer's orders for final delivery of the product. The intervention will utilise professional-level manufacturing engineering software rather than in-house developed programmes which are time-consuming to develop, troubleshoot and maintain and inevitably have limited functionality. Acquiring the ability to be able to rapidly become familiar with a new software packages is a skill expected of graduates in the workplace. Students will be able to examine ‘real’ output from the software utilised by practitioners and they will be

required to select the appropriate data from program outputs for their reports and ignore the inconsequential.

2.9.19.1. Learning Styles and Perry

The literature contains many examples of practitioners examining the relationship between learning styles and academic performance. For this research the inquiry into student learning styles will be to determine which learning styles are present in the student cohort and their relevant proportions in order to ensure that all learning styles present are catered for in the design of the intervention. The levels of student intellectual development will also be investigated to assist in setting an appropriate level of indeterminacy for the student tasks.

2.9.19.2. Benefits

It is expected that the teaching intervention which is the subject of this thesis will go some way to adding to the literature on the application of computers to engineering education and address the issues raised by Spiro, Felder, Shortridge and Ehrmann which were noted earlier. It will be applicable to multiple domains in undergraduate programmes such as production systems, engineering management, and engineering design and will be supported by sound pedagogical theory. It is hoped, also, that it will prompt some 'late adopters' in the field of engineering education to make use of the intervention, or to modify it for their own use. To promote this goal Roger's (2003) suggested attributes, as listed above, will be incorporated into the innovation's design and presentation. The intervention, based around a virtual enterprise, its associated realia and teaching materials will be packaged such that it may be distributed via DVD for use by other practitioners.

3.3. The Research Methodology

3.1. Introduction

This chapter commences with a brief review of the long-running debate which has taken place in the field of education concerning the relative merits of quantitative versus qualitative research methods and the divide between so-called ‘pure’ and ‘applied’ research. The discussion of these methods is followed by sections describing the particular methodological issues relevant to this research, and examining an alternative to the use of traditional randomised controlled trials which have come in for criticism when applied to educational research (Guba and Lincoln, 1989). The development and use of design-based research is reviewed as a procedure to be adopted for this research project and the issues of the researcher’s own ontological and epistemological beliefs are addressed. Measures for ensuring the credibility and transferability of the research are described and finally, a description is given of the planned programme of data collection including details of the instruments to be used for the determination of students’ learning styles (Kolb’s ‘Learning Style Inventory’) and levels of intellectual development (Moore’s ‘Learning Environment Preferences’).

3.2. Selection of the Research Methodology

3.2.1. Research Methodology – Alternative Strategies

Randomised control trials (RCT’s) in education, in which there is a random assignment of students to different interventions and a substantial effort made to control outside variables, have been, as Mayer (2005: 67-81) describes them, “the gold standard for educational psychology since the field evolved in the early 1900s”. A debate, sometimes fierce, began in the 1970’s as a result of a growing concern about the fact that past, and current, experimentally based, education research results, and their associated published papers, seemed to be having no beneficial effect whatsoever on educators’ practices in the classroom (Anderson, 2004). This observation sparked an increased interest in more

phenomenological approaches to research and some scepticism about the effectiveness of the randomised control trial or ‘scientific’ research method when applied to education (Donaldson, 2008, O’Donnell, 2004: 255-260).

Learning research laboratories were criticised for being artificial environments very unlike the classroom settings within which students would normally carry out the activities or learning tasks being investigated.

This scepticism was not new. Almost a century ago, in an article in the first edition of the *Journal of Educational Psychology*, Thorndike (1910: 5-12) recognised that, “...the extreme complexity and intimate mixture with habits in the case of human instincts prevent studies of them, even when made with great care, from giving entirely unambiguous and elegant results” (p.10). He went on to say with regards to:

“...the pathologist or physician who should neglect the scientific studies of bacteria and protozoa. Also the psychologist who condemns these studies (observations, by educators, of children in homes and schools) *in toto* because they lack the precision and surety of his own studies of sensations and perceptual judgments is equally (in error)...”(p.10).

More recently, further ferment in the qualitative-quantitative debate was occasioned in 2003 when the US Department of Education announced its preference for research based on experimental designs over other methods of applied research when it came to giving their approval for funding, quoted by Donaldson (2008). Clegg (2005: 415-428) describes a similar drive to link experimental designs to funding by the UK Labour government and its Minister for Education, David Blunkett, in the early years of this decade.

These moves prompted dismay from many researchers in education and the social sciences and Anderson (2004) suggested that this attitude was, “both naïve and unhelpful”, whilst Scriven (2003), wrote that, “there are many issues of great importance in education ...where it is ethically and/or practically impossible to use RCT’s.”

What constitutes an appropriate research method in many educational research endeavours is a debate that continues today. The discussion stems from the

fundamentally different epistemological positions of the two approaches. Advocates of quantitative research methods, generally adhering to a scientific or positivist epistemology, argue that social and educational research should be objective, context free and completely free of researcher bias. They maintain that social and educational research should be centred on a laboratory-based, randomised, controlled experimental methodology (Neuman, 2006). That is, the same research model that is used successfully and routinely in fields such as physics, medicine and agriculture. Proponents of qualitative research methods, on the other hand, focus on an interpretivist epistemology with an emphasis on meaning. They utilise case studies, phenomenological observations and other activities that aim to explain educational practices from the point of view of the student. There is a middle ground between these two methods – ‘mixed methods’, which, as its name suggests, combines the two methodologies in various proportions and Hiles (1999) writes that, “...there is nothing to rule out using both quantitative and qualitative approaches within the same study”, and Firestone (1987: 16-21) also believes that qualitative and quantitative methods can complement each other.

Nutley (2003: 125-148), in her contribution to the debate, argues for a flexible view on the sources of acceptable data and their analysis and maintains that, “no matter how discrete and pre-existent it appears, evidence is always inextricably intertwined with the actions, interactions and relationships of practice” (p.133). Nutley argues against the separation of research and practice and takes issue with the “hierarchy that privileges the objective ‘facts’ of research over the subjective ‘knowledge’ of practice”. She continues, “There is no such thing as ‘the’ body of evidence, evidence is a contested domain and is in a constant state of ‘becoming’. Thus research is rarely self-evident to the practitioner but varies according to the context in which it is received and deployed”.

A problem with randomised, control trial, experimental methods is that in many situations it is not possible for some of the method’s criteria to be met. For example, it may not be possible to randomly select subjects for the intervention or to use a control group who would not receive the intervention, and it may be impossible to exclude various random influences on the student groups.

These restricting (from a positivist viewpoint) factors also apply to the particular circumstances of this research programme. There is no possibility of utilising a randomly selected control group whose performance could be measured against the group that was subject to the intervention. Subject to ethical approval, one could imagine a situation where, especially in pre-tertiary education, and with parallel classes, one could deliver a course where one stream, or streams, received the intervention and others did not. However, in the circumstances of the current study there is one stream of third-year engineering students only, who as a cohort are competitive, and it is impossible to believe that they would consent to 'missing out' on any teaching method that was perceived to offer some advantage or benefit to their grades. Issues of staffing, teaching space and timetabling also make the utilisation of a control group infeasible. This problem was encountered also by Boles and Pilay (2002: 66-71) who utilised a control group in their work but had to seriously compromise their intervention so as not to run the risk of too much advantage being gained by one group over the other.

In the circumstances of the intervention proposed in this research, it is not possible to control for the learners' prior knowledge and experience which are clearly significant co-variables. It is also difficult to ensure that results are replicable. Furthermore, it is not possible to replicate the equivalent of an experimental double-blind study since the researcher must be aware of the details of the intervention being administered. In fact, the researcher and the individual applying the intervention may be one and the same.

Pre- and post-course assessment techniques are also not applicable since a pre-course assessment of student's attitudes to the course and planned intervention, prior to experiencing them, would have no meaning.

Although a randomised controlled experiment is not appropriate or feasible in this case there are a number of elements that *can* be controlled, manipulated and assessed in the application of the proposed intervention. These are:

- The content and emphasis of the teaching material.
- The pace and sequence of the delivery of the material.
- The number and type of assessment instruments used on the course.

A further problem with the common research approach of comparing a traditionally taught group of students with one taught with a new intervention is pointed out by the

Cognition and Technology Group at Vanderbilt (1993: 52-70), “If the existing approach is unsatisfactory and the tests are more aligned with the instruction in the experimental group than that in the control group, it is often less than illuminating to show that one group of students performed better than the control group”, quoted by Herrington and Oliver (2000). Salomon notes that if what is being studied is a *system* of interrelated factors then it is not possible to study an isolated factor in order to carry out some form of comparison, as each part of the system can affect, and is affected by, the rest of the system (Salomon, 1991: 10-18). He maintains that the study of such complete (systemic) systems [e.g. a course of study in an ill-defined domain] using an analytical and controlled experimental approach is conceptually unsatisfactory.

The systemic character of the course under investigation points to the use, for this study, of a qualitative, interpretivist research method. This approach is also compatible with the constructivist approach utilised in the situated learning pedagogical framework adopted for use in this study and with the researcher’s own ontological and epistemological position.

The use of qualitative and interpretive research methods is now common in the fields of education and social sciences. However, it must be recognised that within the discipline of engineering there is a common conviction that only quantitative research data are of an acceptable level of reliability and repeatability. Engineering lecturers, generally, do not seek to widely explore either various pedagogical approaches or qualitative experimental techniques for their assessment (Heywood, 1995).

In an effort to change the status quo in engineering education, Wankat et al. (2002: 217-237) explained that, “It is almost impossible to construct an educational research study in which potentially confounding factors can be clearly identified and their influence eliminated. Students are far more difficult to categorize than I-beams or transistors or even fruit flies” (p.91), quoted by (Borrego, 2007: 91-102). Borrego points out that there are differences between the fields of engineering research and educational research which preclude the application of conventional engineering research standards of rigor to engineering education research. That is not to say of course that rigor cannot be achieved by other approaches and this issue is discussed in Section 3.3. Wolf and Crookall (1998: 7-19) also support the use of interpretive research contexts such as this

current study. They maintain that classically acceptable experimental research used in the physical sciences is impossible to duplicate in realistic educational situations especially in the area of educational simulation given its open-ended and experiential nature.

In addition to the debate about research methodologies, the literature in the fields of both education and engineering have been concerned with discussing a somewhat parallel issue — the conventional practice of labelling research either ‘pure’ or ‘applied’. The relative value of basic versus applied research has been discussed by many working in the fields of computer-aided education, multimedia and instructional design including Merrill et al. (1996: 5-7). Higgins et al. (1989: 7-18), quoted by Reeves (2000), maintain that evidence of the debate in these fields is seen in the division of one of the leading journals in the field, ‘Educational Technology Research and Development’, into separate ‘Research’ and ‘Development’ sections.

An influential contribution to this debate was the publication of ‘Pasteur’s Quadrant’ by Donald Stokes (1997) in which he makes a strong case for reassessing the traditional, restrictive separation between ‘basic’ and ‘applied’ research which has for so long been a part of political, scientific and engineering cultures. This separation promoted what is now the well-known, one-dimensional model of progress within science and engineering with basic research leading on to applied research, then to product and process development and, finally, on to product production and operation. Basic and applied research are represented as being on a one-dimensional continuum, Basic —> Applied, and research cannot be closer to one of the poles of this continuum without being further away from the other.

Stokes argues that the division of research activities into ‘Basic’ and ‘Applied’ has never been strictly accurate and refers to the work of Louis Pasteur to make his point that any attempt to place the work of many researchers on this one-dimensional continuum produces a contradiction. He points out that Pasteur was a researcher, committed not only to understanding the fundamental basis of the micro-biological processes he discovered, but committed also to applying this knowledge to control the effects of the micro-biological processes on animals and humans and problems such as anthrax and cholera.

In order to eliminate this categorisation, Stokes argues that it is necessary to amend the traditional view of a one-dimensional spectrum to a two-dimensional one. Using this 2D model and dividing the spaces into quadrants, as shown in Figure 3-1, the anomaly is resolved. Pasteur’s research occupies the upper right quadrant representing research inspired by both a search for fundamental knowledge and its practical application.

		Considerations of Use	
		No	Yes
Quest for fundamental understanding	Yes	Pure Basic Research (e.g. Bohr)	Use-Inspired Basic Research (e.g. Pasteur)
	No		Pure Applied Research (e.g. Eddison)

Figure 3-1: Two Dimensional Spectrum of Research

(Adapted from Pasteur’s Quadrant: Basic Science and Technological Innovation, Stokes 1997)

As Richard Hake (2004) points out, many researchers in education now work in Pasteur’s interdisciplinary, use-inspired, basic-research quadrant carrying out what is known as ‘design-based research’. Terry Anderson (2004), in a keynote address to the third EDEN Research Workshop, supports the adoption of this approach to the basic/applied issue and suggests that, “...we need to develop new research paradigms that bridge the gap between scholarship and practice so as to make fundamental improvements to the quality and cost effectiveness of these [teaching] services”.

This current research study similarly adopts a ‘use-inspired’ research philosophy with the intention of it resulting in a practical teaching intervention informed by pedagogical research.

3.2.2. Appropriate Methodology - Selection

With this background of alternative research philosophies and attitudes to research in mind, a review of the relevant literature was carried out to examine past and current professional educational research practice as it might apply to the design and evaluation

of the proposed intervention. There are a number of relevant research techniques present in the fields of education and the social sciences and the consideration of the work of a number of researchers were additional influences in the determination of a suitable research methodology.

Similar concepts to Stokes' 'Use-inspired basic research' have been proposed by a number of researchers in education. These have been variously described as 'formative research' by Newman (1990: 8-13), 'design experiments' by Brown (1992: 141-178) and Collins (1992: 15-22) and 'development research' by van den Akker (1999: 1-14), 'design research' by Edelson (2002) and 'developmental research' by Richey et al. (2003: 1099-1130). Each of these manifestations has a slightly different emphasis but the basic approaches are similar.

Reeves (2002) explains clearly the differences in the apparent goals of the positivist, experimental milieu and that of design-based research and argues for more academic staff to pursue research into education. He points out that, "The overall goal of research within the prevailing positivist tradition is to develop long-lasting theories and empirical principles that can be handed off to practitioners for implementation and that regards theory above, and apart from, practice. While this experimental approach may work in fields such as chemistry and biology it has not been very successful in the social sciences, including education". He describes design-based research, or development research, as a pragmatic epistemology that regards theory as being collaboratively shaped by researchers and practitioners, "The overall goal of development research is to solve real problems while at the same time constructing design principles that can inform future decisions".

In defining the meaning of his related concept 'development research' Van den Akker (1999: 1-14) writes:

"More than most other research approaches, development research aims at making both practical and scientific contributions. The ultimate aim is not to test whether theory, when applied to practice, is a good predictor of events. The interrelation between theory and practice is more complex and dynamic: is it possible to create a practical and effective intervention for an existing problem or intended change in the real world? An iterative process of 'successive

approximation’ or ‘evolutionary prototyping’ of the ‘ideal’ intervention is desirable. Direct application of theory is not sufficient to solve those complicated problems”.

This work will examine, and adopt, the approach termed ‘design-based research’ as it enjoys the broadest influence in the literature and has been utilised by a number of prominent researchers in education including Herrington (2006: 3164-3173). Herrington argues that research into educational technology has, in general, not changed the methods used by educators as the primary aim of such research has been to prove rather than to improve. She says that many researchers carry out studies designed to show that one medium is superior to another rather than seeking ways to improve methods. Herrington believes that design-based research provides a useful model for taking innovations from initial conception to successful implementation.

The general characteristics of design-based research methodology have been the subject of a number of books and journal papers. The most often cited works being those of Brown (1992: 141-178) and Collins (1992: 15-22) although there seems to be a gap in the literature on this methodology, from Brown and Collins’ initial work in the 1990’s, of about a decade. However, with the publication of several special issues of refereed journals devoted to design-based research in the period 2002-2004, e.g. ‘Educational Research’, ‘Journal of the Learning Sciences’ and ‘Educational Psychologist’, a considerable amount of material has now been published.

Design-based research adopts an action, interventionist and iterative posture to learning research. It is centred on the participants of the study and collaborates with them. It uses ongoing, in-situ, monitoring of the sources of success or failure of various versions of a designed teaching intervention to provide immediate or, at least, timely feedback on the results of the intervention (where the intervention may be any one of a number of influences on the learning environment). As made clear by the Design Based Research Collective (2003: 5-8) the intervention, or artefact, may consist of, “activity, structures, institutions, scaffolds or curricula”. They point out that, “Importantly, the scope, and the questions required to be answered in a design-based research project may change as the design progresses”.

Design-based research was described by Shavelson et al. (2003: 25-28), as follows:

“[Design-based]...research, based strongly on prior research and theory and carried out in educational settings, seeks to trace the evolution of learning in complex, messy classrooms and schools, test and build theories of teaching and learning, and produce instructional tools that survive the challenges of everyday practice”.

Barab and Squire et al. (2004: 1-14) elaborate on this description describing design-based research as, “a series of approaches with the intent of producing new theories, artefacts and practices that account for, and potentially impact [upon] learning and teaching in naturalistic settings”. Thus, importantly, a design-based application must be theory driven and in this respect it differs from the traditional case study in education. Cobb et al. (2003: 9-13) emphasise the iterative nature of the process, “The design content is subject to test and revision, and the successive iterations that result play a role similar to that of systematic variation in experiment”.

As noted by Cobb, a key characteristic of the methodology is the interactive nature of the process as conjectures are generated, and perhaps refuted, and new conjectures developed and subjected to testing. It is an iterative design process containing cycles of invention and revision. The outcome of an iterative cycle is a framework of theory helping to describe the outcomes and which can be used to specify the focus of investigation during the next cycle of inquiry to again inform and improve the application. Design-based research may be undertaken by a single worker acting as both researcher and implementer of the intervention. This dual role affording the opportunity to observe closely how research questions, design questions and questions of implementation and revision interact with each other.

One criticism that has been levelled at design-based research is what Brown (1992: 141-178) called the “Bartlett Effect” or the difficulty of avoiding a tendency to select, or pay more attention to, data that tend to confirm the researcher’s expectations regarding the outcomes of an intervention. This issue is addressed generally in the methods to be used to ensure the credibility of the research (Section 3.3).

The design-based research action process has the added advantage that, since the intervention is tested in the hurly burly of the lecture theatre, tutorial room or computer

laboratory, all of the external factors that might affect the intervention for good, or ill, are present, unlike the situation when teaching innovations are tested in a controlled laboratory environment.

Another important feature is that the method is itself both open-ended and also seeks information about open-ended questions such as, ‘what are the factors that improve student motivation in multimedia courses?’ rather than, ‘are multi-media methods of presentation better than traditional lectures in motivating students?’

The Design-Based Collective (2003: 5-8) are leading researchers in this field and, usefully, set out the following five characteristics of the design-based approach:

1. The central goals of designing learning environments and developing theories or ‘proto-theories’ of learning are intertwined.
2. Development and research take place through continuous cycles of design, enactment, analysis, and redesign.
3. Research on designs must lead to sharable theories that help communicate relevant implications to practitioners and other educational designers.
4. Research must account for how designs function in authentic settings. It must not only document success or failure but also focus on interactions that refine our understanding of the learning issues involved.
5. The development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest.

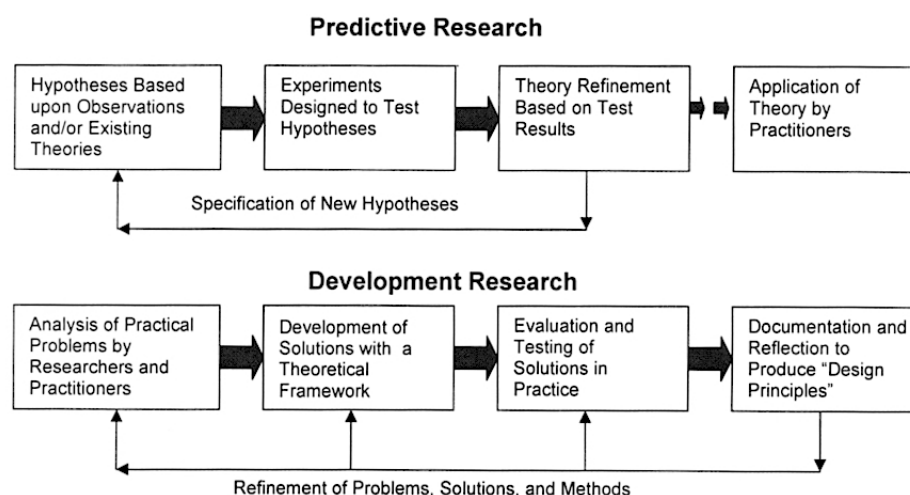


Figure 3-2: Predictive Research & Design-based Research Compared

(After Reeves, 2000)

Figure 3-2 illustrates the differences in between predictive research, as usually applied to ‘laboratory’ and experimentally based research efforts, and design-based research.

The methodology can be likened to the design and testing of a product in engineering. The educational intervention (c.f. product) design cycle begins with a product concept based upon relevant pedagogical theories (cf. engineering fundamentals – mechanics, thermodynamic principles, etc.). This is then followed by the creation of a first working intervention (cf. product model or prototype). The prototype is then tested and the data collected during the testing is used to refine the design. This cycle of design, test and re-design is carried out as many times as required. In fact, as in product design and production, the cycle may never be completely terminated. Changes in technology, customer requirements, delivery methods, etc. will mean the intervention (product) can never be said to be ‘finished’ as it chases a moving target.

3.2.3. Design-Based Research – Steps to Implementation

A starting point in the process of developing this design-based research study is to define a workable process (Jonassen et al., 2007: 45-52). The study may be structured as a set of systematic steps that can be followed during a micro-cycle (within a semester’s course) as well as the total research programme macro-cycle. These steps, modified from Jonassen, will be as follows:

Craft the Design: Develop the overall framework for the entire course including the syllabus, course schedule, and learning goals. For each assignment develop multimedia materials and simulations that are designed to meet the course goals. Create an intervention artefact to assist in the achievement of the required learning outcomes.

Test the Design: Implement the intervention while the course is in progress. Test the concept to ensure the computer technology and software is working as required. Collect data through questionnaires and observation.

Analyse the Data: Feedback from the evaluation surveys provides information about the perceived value of the intervention for learning. Comments submitted by students who complete the evaluations provide insight into the nature of technical problems or misunderstanding about the multimedia and other software content.

Build Theory: After analysing the data determine if there is evidence to support revision or extension of the theories applied during the design of the intervention. For example, if the intervention is rated poorly by students is it because of a flaw in the design or in the theories guiding the design? If students are not using the intervention is it because of technical problems or is it a matter of motivation? These questions can be studied in the next iteration cycle.

Revise and Retest: Revise the design of the intervention to improve it and also to continue testing theory. This process is carried out until, as van den Akker (1999: 1-14) says, “a satisfying balance between ideals and realisation has been achieved”.

3.2.4. Ontological and Epistemological Issues

The research methodology selected must be congruent with the researcher’s perceptions about ‘what can be known’ (ontological beliefs) and ‘how it can be known’ (epistemological beliefs). These perceptions, or the paradigm within which the research will be carried, out will influence the selection of the research methodology and must be made clear (here paradigm is defined as a basic set of beliefs that deals with the ultimates or first principles — Guba and Lincoln (1994: 105-117). Indeed, Hiles (1999) suggests that disciplined inquiry contains four linked aspects: the adopted paradigm or assumptions about reality and knowledge; strategy, the choice by which the research is to proceed, e.g. research question or hypothesis testing; methods, the procedure for the collection of data; analysis, the techniques for the analysis of the data. The adopted paradigm, described below determines the choices that can be made for the strategy, methods and analysis aspects which are detailed elsewhere.

This researcher takes a constructivist and relativistic stance believing that reality is perceived by individual cognitive constructions. Each individual receives or interprets reality or facts differently e.g. as demonstrated by the common phenomenon of widely differing ‘eye-witness’ reports of the same event. It is also believed that social influences and experience are important sources for knowledge construction and that knowledge constructions may change through experience and growing maturity of the construct. Transfer of knowledge can take place through vicarious experience e.g. narrative and story.

Consistent with a constructivist approach, a relativistic epistemological point of view is adopted in which the researcher and the subject are linked, in the case of this study, through the application of the intervention and its evaluation and revisions. The research findings are created as the study continues through various iterations of the design.

In congruence with the researcher's ontological and epistemological positions, the methodology to be adopted for data collection and analysis in this work is a dialectical one based on interaction between subject and subject, and subject and researcher. Data will be collected through student observation, questionnaires and interviews.

This study will adopt a primarily qualitative research methodology because it will deal with students' attitudes to an ill-defined course and their subsequent motivation and engagement with the course via the proposed intervention. These are somewhat intangible values and cannot be accurately measured. A quantitative Likert scale will be used to gather data on the student's attitudes from their perspective but these perceptions cannot be rooted in concrete values. There is no absolute scale upon which we can quantify student-to student levels of motivation or engagement.

3.3. Ensuring Trustworthiness of the Study

When conducting quantitative design studies the issues of validity (internal and external) and reliability need to be addressed. Internal validity is defined as the degree to which the design of the experimental study controls or prevents extraneous variables from influencing the results (Ross and Morrison, 2004: 1021-1044). External validity refers to the extent to which the results of the study can be generalised to other groups in other settings (Neuman, 2000). Reliability is a measure of the dependability or consistency of the study results.

In interpretative qualitative studies, such as the present work, the issues of internal and external validity and reliability require to be re-examined. Guba and Lincoln (1989), in an important work, argue for a new set of 'validity' measures or "trustworthiness criteria". They concede that validity and reliability criteria are perfectly reasonable and appropriate for research that is grounded in a positivist paradigm but, "are unworkable within a constructivist approach".

Guba and Lincoln argue that internal validity is basically a measure of the way that things really are and how they work. They suggest a new criterion, ‘credibility’, which is more meaningful within a constructivist inquiry. They define credibility as the extent to which the research study findings represent not “a presumed ‘real’ reality, out there somewhere”, but rather the multiple constructs that are held by the students in the study. Techniques are suggested for increasing the credibility of results. These include the following:

- Prolonged engagement, a substantial involvement at the site of, and within the inquiry.
- Persistent observation, sufficient to add depth to the inquiry.
- Member checking in order to verify that what was recorded in interviews was what was intended to be communicated.
- Negative case analysis.

Guba and Lincoln do not specifically nominate triangulation (the use of multiple corroborative data sources) as a technique for assisting with credibility. In fact they believe that it carries too positivist an implication, which is: “that there actually exists unchanging phenomena so that triangulation can logically *be* a check on it” (p.240). Nevertheless use of the method has been widely reported in the educational literature and, relevantly, Agogino et al. (2006: 617-625) describe its use in the investigation of the factors contributing to success in mechanical engineering design teams.

Methodological triangulation is the combination of dissimilar methods of data collection such as interviews, observations and surveys to study the same phenomena or factors and using the same units of measurement i.e. individual student data. Within an interpretive research paradigm most data collected will be qualitative but quantitative data may also be appropriate. The use of triangulation may help to overcome any weaknesses or bias that may be present within one of the data sources used. However this use of triangulation is controversial and Angen (2000: 378-395) quotes Mathison (1988: 13-17) who argues that “triangulation is as likely to result in inconsistent or contradictory evidence as in convergent findings”. In any event the use of triangulation will be of benefit in making the data set more fully-developed and comprehensive.

The concept of external validity, or generalisability, has no meaning if the realities about which generalities are to be made take different forms in different students based upon

the student's individual experiences, both in the past, and, in this case, with the proposed intervention. Guba and Lincoln suggest 'transferability' as a parallel to external validity. The criterion of transferability is met by maintaining a detailed record of the time, place and context within which the research study was carried out.

'Dependability' is proposed by Guba and Lincoln as parallel to reliability as it deals with the constancy of the data collected over time. In experimental studies, changes in methodology or hypotheses would lead to exposing the study to the charge of unreliability. However, in naturalistic methodologies these changes are the expected products of an emerging intervention design. Dependability can be demonstrated by a documented and 'trackable' process; a measure of the quality of the research programme. Guba and Lincoln also describe objectivity as a construct which is no longer useful in a constructivist context and propose that, since the core issue is of researcher neutrality, a more useful criterion would be that; of 'confirmability'. That is the level of assurance that the research data originated in the original sources and that the methods by which they were analysed and conclusions drawn can be confirmed.

Table 3-1: Establishing Trustworthiness

Criterion	Method	Activity for this Study
Credibility	Prolonged Engagement	Spending 12 weeks in course environment to aid in co-construction of meaning between researcher and students.
	Persistent Observation	Substantial periods of observation to give depth to findings.
	Triangulation	Use multiple sources of data – questionnaires, Interviews, observation, student assignments.
	Member-checking	Responses to interview questions checked by participants.
	Negative case analysis	Examine data that do not support or contradict usual patterns.
Transferability	Thick description	Detailed account of intervention design, iterations and application.
Dependability	Audit Trail	Record of steps taken in the research study, reports, notes and instruments.
Confirmability	Triangulation	Use multiple sources of data – questionnaires, Interviews, observation, student assignments.
	Reflexivity	Report research perspectives, positions, values and beliefs.

3.4. Data Collection Methods

Data concerning the students' responses to the various iterations of the learning intervention were collected using several methods. Questionnaires, individual and group interviews, and observation of student behaviour were used to assess students' perceptions of, and experience with, the multimedia concept.

3.4.4.1. Questionnaires

Questionnaires, based upon a Likert scale were used when answers to specific questions were required. These were expected to be useful in the early stages of the work in order to ensure that the basic concept of the intervention had been welcomed, in general, by students. In the final stages they assisted in determining to what extent the intervention had helped to address the research questions.

A Likert scale is a common method of data collection for affective variables such as attitudes, preferences and opinions. It is an ordinal measurement scale representing a ranking of responses which, in this study, contains a single group of respondents ('Manufacturing Systems' students). The results were analysed using descriptive techniques - modes and frequencies to measure tendencies.

There has been some debate about the effectiveness of Likert scales for measuring attitudes. For example Gall *al.* (1994) believe that Likert type scales, "reveal little about the causes for answers" and that, "they have limited usefulness". However they are widely used in educational research and Neuman (2000), quoted by Page-Bucci (2003), supports their use maintaining that, "the simplicity and ease of use of the Likert scale is its real strength". In the case of this research the 'cause of the answers' were examined in the interviews.

Another advantage of the Likert scale is its ease of completion by respondents. An important factor when students are probably over surveyed and requested to complete numerous questionnaires, evaluations and surveys in the course of their engineering degree studies.

From a practical point of view, there is also some debate about whether, or not, to utilise odd or even numbers of responses for each Likert item. Scales with an even number of response options omit a neutral position, and, it is argued, force respondents to make a decision one-way-or-another. Nevertheless, some students may well have a truly

‘unsure’ stance in which case forcing them to decide on an alternative response reduces the reliability of the instrument. For the purposes of this study some students may well be undecided or neutral about an item and so a five point Likert scale was utilised. Both five and seven-point scales have been shown to have improved reliability and validity over those with fewer response points whilst more finely graded scales with more points do not demonstrate a resulting improvement in reliability or validity (Dawes, 2008: 61-77) and studies show that respondents are not able to easily determine their point of view on a scale with more than seven points.

3.4.4.2. Interviews

Interviews can be classified as structured, semi-structured or unstructured and may be carried out with individuals or with groups (Fontana and Frey, 2000: 645–672). The purpose of the interview is to gather data to assist with solutions to the study’s research questions. The benefits of a structured interview are that ‘tick-the-box’ style forms can be used with a set list of questions to simplify and speed data analysis, and interviews can be completed relatively quickly. The disadvantages are that participants can only make a limited response to the questions and further ‘probing’ questions cannot be asked by the interviewer.

Semi-structured interviews have the advantage of allowing the participants to make a greater contribution and for the interviewer to ask additional questions to probe an issue or response further should it be required. The disadvantages are more complex data analysis and additional time required for the interview, and later write-up and analysis. Also required are some interview skills on the part of the interviewer.

Unstructured interviews were rejected as a methodology because of the chance that particular topics for which data was required may not be well covered and that too much irrelevant data may be collected.

For this study the semi-structured interview format was selected. Primarily, this was because it allowed for a basic set of questions to be prepared to ensure that all the required topics were covered. It also gave flexibility for supplementary questions to be asked and to explore areas suggested by the participants not previously occurring to the interviewer. The semi-structured interview also allows data to be collected about complex feelings and attitudes that can’t be easily determined by structured interviews

or observational and questionnaire techniques. The researcher's previous interviewing experience in engineering management and personnel recruitment was considered to be sufficient to ensure that the required level of interviewing skills were present.

To ensure credibility and truly reflect their perspectives the participant's own words were used in reporting wherever possible. A good rapport between interviewer and participants was also of benefit. Credibility was also assisted by the interviewer taking care not to inadvertently send signals vocally, by tone of voice or body language, which may have influenced a respondent's answers. The issue of individual respondents not being completely frank about an item was minimised by ensuring that a reasonable sample size of students are interviewed using the same set of questions.

Member checking was used following the interviews to help ensure credibility within the study. The interviewer's notes were to be read back to the participants to check that their comments and emphasis have been correctly recorded.

3.4.4.3. Observation

In order to collect first-hand data on the reception and use of the intervention, and the students understanding of the topics and software tools, an observational technique - participant observation, was used (Babbie, 2007). A feature of participant observation is the interaction between the observer and the students and it is a technique commonly used in educational research (Savenye and Robinson, 2004: 1045-1072). Observations are a valid qualitative research data collection method when used and planned deliberately and recorded systematically (Merriam, 2002: 439).

In this study the researcher's role was as observer-participant as in the initial tutorial session for a particular task the researcher demonstrated the software to be used and described some typical problems and their solutions. For subsequent tutorial/lab sessions on the same task the researcher took an observer role only. Not everything that occurs can be recorded so field note notes were used to record data and the notes were analysed immediately after the observation session. Again, because not everything can be recorded it was determined beforehand that emphasis would be placed on noting students' initial interactions with the intervention and then the interactions between students as they progressed through the task. These areas were selected as they had an important bearing upon the research question issues - motivation, engagement and

ability to resolve indeterminate problems. Levels of student collaboration were also noted.

For the last series of observations in iteration four a technique from manufacturing engineering, random activity sampling, was used. This technique involves making observations at a number of predetermined, but random, intervals over a period of time and recording what is happening at that instant. The random times were generated by the Excel random number generator and the observations were recorded on a chart. Five students were also selected at random for the exercise and a total of 10 events each was recorded within an hour. Student activities were recorded for four categories of continuous type activity such as working on task. Four categories of intermittent activities such as moving to help another student were also recorded, as and when they occurred. A copy of the Observation chart is included in Appendix E.

3.4.4.4. Kolb's Learning Styles Inventory

The learning styles inventory (LSI) by David Kolb identifies a person's individual learning preference for one of four learning styles: diverging, converging, accommodating or assimilating, using a self-reporting, forced-choice format, instrument. A detailed description of these styles was given in Chapter 2, Section 2.7.15. The self scoring LSI instrument consists of two documents; the Learning Style Inventory scoring sheet and the 'Cycle of Learning' result sheet. The scoring sheet contains 12 items and brief instructions for respondents on how to complete the instrument. Each item consists of a sentence stem (e.g. 'When I learn...') with four selectable endings. Each of the four endings is ranked by the respondents according to how well they think the endings fit how they go about learning. The endings are rated: 'Most like me' = 4, 'Second most like me' = 3, 'Third most like me' = 2, 'The least like me' = 1. Ties in ranking are not allowed. Respondents add the randomised rankings, according to a guide provided, to obtain scores which indicate their preferences for each of the four learning modes: concrete experience, CE (experiencing); reflective observation, RO (reflecting); abstract conceptualisation, AC (thinking); and active experimentation, AE (doing).

A completed LSI provides six scores. Four of the scores measure a respondent's relative preference for the primary learning modes, whilst a further two combination scores

measure the respondent's preference for 'thinking' over 'experiencing' (AC-CE) and for 'doing' over 'reflecting' (AE-RO).

The totals for each of the four primary learning modes may be plotted on a quadrant chart to provide a graphical representation of a respondent's preferences with regard to each of the four constructs. The combination scores may be plotted on a scatter diagram with axes AE-RO and AC-CE.

Since its initial publication in 1976 there has been a great deal of research published on the subject of Kolb's Learning Styles Inventory (Marshall and Merritt, 1986: 257-262), and it has been through a number of revisions aimed at improving its reliability and validity.

The version of the Kolb Learning Style Inventory used for this research was version 3.1, 2005. This version is the latest revision of the LSI and incorporates the 'randomised questions' format adopted in 1999 to improve test-retest reliability. Version 3.1 also includes new normative data based on a larger and more diverse sample (N=6,977) of LSI users than previous versions.

3.4.5. Reliability and Validity of the LSI

A research report from the Learning & Skills Research Centre (Coffield et al., 2004) examined 13 learning style models. The authors report on a long and widely debated dispute over the reliability of LSI although at the time of writing the third version was still undergoing examination. They remark that the model has a low predictive validity, but point out that it was not specifically developed for this purpose but as a self-assessment exercise. In a detailed critique Webb (2003) writes that the Learning Style Inventory is faulty and recommends that the operational evolution of learning styles as a combination of contiguous modes of learning be re-evaluated.

Kayes (2005) in examining Version 3 of the instrument found that updates to the instrument have addressed some of these concerns, especially when the instrument is used for self-diagnosis of individual learner preferences as it will be in this study.

Permission to use the Kolb LSI, version 3.1 instrument was granted with a signed agreement by the licensees for the instrument – Hay Group, Boston MA.

Curry (1983) found an average test-retest correlation of 0.58 for the Kolb LSI amongst a sample of 27 fourth year medical students over a span of three months and an internal consistency average of 0.69 amongst a sample of 687 undergraduate and graduate students in the management sciences and, in a later paper, reported “strong reliability” and “fair validity” for the instrument (Curry, 1987), quoted by DeBello (1990: 203-222).

In a later study Willcoxson and Prosser (1996: 251-261) found Kolb’s learning style inventory to be highly reliable and indicated in their report that there is evidence for its validity.

3.4.5.1. Moore’s Learning Environment Preferences instrument

The Learning Environment Preference (LEP) instrument developed by Moore is based upon Perry’s scheme of intellectual development. The LEP survey covers five domains concerning epistemology and learning: view of knowledge and learning; the role of the instructor; the role of the student and peers; classroom activities; and the role of evaluation and grading (Moore, 2000). Each domain contains 13 listed statements and respondents are asked to rate each one on a four-point Likert scale, from ‘not at all significant’ to ‘very significant’, and then to rank the top three items overall. The statements in the lists increase in complexity from top to bottom and each list contains one ‘dummy’ item. This dummy item is a complex sounding statement which on reflection is seen to be incomprehensible and is present to provide an indication as to whether, or not, participants are selecting preferences just because they sound profound. The instrument takes about thirty to forty minutes to complete and students are reminded that they should be concerned in their responses with their *ideal* learning environment and not any particular course or class of which they have experience.

Scoring of the completed instruments was carried out by William Moore at the Center for the Study of Intellectual Development, Olympia, Washington, DC.

3.4.6. Reliability and Validity of the LEP

The internal consistency of the LEP has been evaluated by Moore. Moore (1989: 504-514), as quoted by Felder and Brent (2005: 57-72), used an item factor analysis and two rating experts to examine the content validity of the instrument. He carried out a reliability study, using a sample of 725 students attending seven colleges, with 47% men

and 53% women. The cohort consisted of 38% Year 1, 34% Year 2, 10% Year 3 and 18% Year 4 students. For each set of items keyed to a specific position across all domains, Cronbach's alpha reliability coefficients were 0.81, 0.72, 0.84, and 0.84 respectively for position 2 to position 5. The lower figure for position 3, Moore concluded, was that position 3 lacked the conceptual clarity of the constructs in the other subscales. A one-week test-retest reliability study suggested a reasonable level of stability of the instrument over time with a correlation of 0.89.

A factor analysis was used to investigate construct validity. Moore believed that four factors comprised the LEP and the patterns of significant loadings on each of the factors persuaded him to state that the factors did represent the four Perry positions (2 to 5) in a general sense (Brooks, 1998). Moore found a consistent upward hierarchical movement from positions 2 to 5 and a strong correlation between Perry's positions and other related constructs such as the Measure of Intellectual Development produced by Mentkowski et al. (Mentkowski et al., 1983), quoted by (Wilson, 1996), which is a parallel measure of Perry's positions.

Moore (2000) notes that "... the LEP has proven to be a solid research instrument and has been used fairly widely throughout the U.S. and Canada at a variety of educational institutions". Brooks (1998) in his thorough review of Perry's scheme, and the instruments developed to assess intellectual development, suggests that the LEP instrument "shows some promise as reliable and valid objective measure of the Perry scheme".

Hofer and Pintrich (1997: 88-140), however, in their extensive review of the development of epistemological theories, criticise aspects of the LEP, and other common written assessment instruments, as seeming to confound perceptions of educational experience with epistemology and containing issues of classroom learning and teaching which were not a part of Perry's original method. The LEP however is still able to discriminate well between dualistic and relativistic positions.

4. Intervention Design and Application

4.1. Introduction

The requirements for, and selection of, a suitable pedagogical framework for the intervention, i.e. situated learning, were determined in Chapter 2, Section 2.5.11. This chapter describes the development of the proposed computer-based multimedia teaching tool, incorporating all the relevant critical elements of a situated learning environment.

In designing a computer-based model of a virtual enterprise, to simulate the operations of a manufacturing system, it must be borne in mind that reality can never be fully replicated. This means that decisions must be made about the model's level of fidelity and about the compromises that must be accepted as a consequence of limitations in the resources of time and budget. For example, there will be no examples of *interactive* 3D models of machine tools such as those sometimes used in machining simulations (El-Mounayri et al., 2008: 183-189, Hsieh and Hsieh, 2001: 569-579, Ong et al., 2002).

Decisions are also required as to which topics in the subject domain should be included in the model and which omitted. Once these content topics have been selected then further decisions must be made as to how they will be modelled and to what level. Not everything in the real-world is of the same importance and this fact must be reflected in the model. Some tasks, or objects, will be at the forefront while others of lesser importance are relegated to the background. For example, the movement of raw material and components within a manufacturing organisation requires much planning and if done inefficiently can lead to lost production, scrap and financial penalties.

Nevertheless, for this particular generation of the intervention material handling will be a background activity. It is present but not a major feature of any activity.

For this design, the topics required to be given prominence will be those of fundamental importance to manufacturing systems engineers and which are core components of their

responsibilities as determined by industrial stakeholders, see Section 4.2.1.1. These topics include, plant and equipment layout, work-station design (ergonomics), and production planning and scheduling. Other important areas, to be covered in the course but given less emphasis in order to reduce complexity, included inventory management and work measurement. Factory data collection, data buses and networks, whilst also important, were also not be at the forefront because these areas are generally not the prime responsibility of the manufacturing systems engineer but IT personnel.

The most successful learning environments surveyed by Herrington and Oliver (2003: 2115-2121) did not need to contain ‘photo-realistic’ simulations but ‘cognitive realism’. That is, the extent to which the simulation promoted ‘realistic problem-solving processes’. The design of this current intervention aimed to promote such ‘cognitive realism’ with an appropriate level of virtual enterprise modelling,

The design of this intervention proceeded in accordance with the ADDIE methodology. This is a common generic design process used in instructional design by those developing teaching materials for the web and other computer-based instructional settings. It consists of the phases of Analysis, Design, Development, Implementation and Evaluation. In detail the phases are:

- Analysis: The designer identifies the learning problem, the goals and objectives, considers the students’ prior knowledge, the learning environment, the schedule for completion and any other relevant data.
- Design: The process of specifying the learning objectives, the pedagogical framework, content, graphic design and user-interface.
- Development: The production phase for the creation of the content, computer material and coding.
- Implementation: In this phase training for those presenting the instruction is given and the design is delivered to students.
- Evaluation: In this phase, post delivery, an evaluation of the effectiveness of the training materials is carried out and revisions are made as necessary.

This formalised design process has substantial similarities to the methods traditionally used by engineers to develop quality control and other systems in manufacturing. For instance, the traditional Shewhart Cycle of continuous improvement: Plan – Do – Check – Act (Shewhart, 1980).

A modification to the standard ADDIE model borrowed from engineering is ‘rapid prototyping’ (or continual feedback) which has sometimes been cited as a way to improve the generic ADDIE model (Stokes and Richey, 2000: 63-80). This continual feedback was undertaken during the implementation of the design in order to rapidly correct any technical problems with the computer delivery of the intervention.

As a result of the findings of the review of the relevant literature in Chapter 2 it was determined that the design would incorporate:

- a) A full narrative structure presenting a detailed and valid scenario to encourage the willing suspension of disbelief by users.
- b) The provision of an authentic context in which the reasons for mastering a particular topic or skill are made clear.
- c) The provision of authentic content with ‘life-like’ and ill-formulated tasks to be undertaken to provide multiple perspectives of the problems and opportunities for practicing relevant skills.
- d) Tasks with, as far as is possible, appropriate depth and duration to encourage immersion and ownership of the activity.
- e) The opportunity to engage in team-based problem solving.

The work undertaken in the individual stages in the ADDIE design process is described below.

4.2. The Intervention – Design & Development

4.2.1. Stage 1: Analysis.

The learning problem being addressed and the goals and objectives of this research programme have already been considered in this document and are known. Also known is the general level of students’ prior knowledge, the university learning environment within which the intervention will be made and the schedule for completion. What needs to be determined at this stage are the topics to be covered and the tasks to be set.

4.2.1.1. Topic selection

The role of a manufacturing engineer is to plan, organise, integrate and manage people, materials, time and money in order that products and services may be supplied at the required cost, quality and time whilst, at the same time, meeting the goals of the organisation, providing for the needs of those employed, and society in general.

To carry out these duties manufacturing engineers must be knowledgeable in such subject areas as mechanical engineering, production engineering and engineering materials, and possess supporting knowledge in other fields such as computer networks and engineering management (Hung et al., 2003: 734-737).

The decision about which topics in these various, relevant, subject areas to include in the intervention was made following a consultation process with a number of New Zealand manufacturing engineering companies, the Auckland Manufacturers Association, members of the former Institution of Production Engineers, and discussions with teaching colleagues.

The consultation process began with discussions held with senior staff at the companies listed in Table 4-1 to obtain their views of the topics that should be included in an 'ideal' manufacturing systems course. The companies were selected to represent a cross-section of manufacturing activities from primary products (steel) through to complex special purpose machinery. The companies selected also varied in size, production volumes and product value.

Table 4-1: Companies Consulted for Course Input

Company	Description
Buckley Systems Limited	Low volume, high value and precision manufacturers of specialist production machinery.
Croxley Group	High volume, low value consumable paper products.
Electropar Limited	Medium volume, medium value electrical equipment
Faulkner Collins Limited	Medium/high volume wire products.
Fisher & Paykel (Health Care) Ltd.	Medium/high volume, multi-process/material, medical equipment.
Fisher & Paykel (Laundry Div.) Ltd.	Medium/high volume, multi-process/material, consumer goods
Gallagher Group	High volume, medium value agricultural/horticultural
BHP New Zealand Steel Limited (Now BlueScope Steel)	High volume, supplier of primary product.
Spiral Welded Pipes Limited.	Project-based production volumes, pipe suppliers to the construction industry.
Southcorp	Medium volume, medium value electrical consumer products.
SuperLux Limited	Medium value, medium volume, lighting equipment.
Technatools Limited	Low volume, medium value, woodworking machine tools.

Information gathered from these sources was discussed with colleagues in the Manufacturing Systems Group at the University of Auckland. An amalgam of the ideas and suggestions received from this consultation process led to the list of suggested topics in the following table, Table 4-2.

Table 4-2: 'Ideal' List of Manufacturing Systems Course Topics

Aggregate planning	* Automation systems
* CAD/CAPP integration	Capacity planning (make or buy)
* CNC programming	Data collection
E-Commerce	* Ergonomics
* Facility layout	Factory networks
Finite resource scheduling	Forecasting
Industrial data buses	Inventory management
JIT & Lean manufacturing	* Job design and work measurement
Kanban	Learning curves
Line balancing	Linear programming and transport models
Systems Analysis	Management information systems
Materials handling	Models, simulation and queuing theory
MRP & ERP	** Operations Management
* Product design for manufacture	Productivity
** Project management	** Quality management
Reliability	** Statistical Quality Control
Supply chain management	** TQM, Quality function deployment
* Work standards and measurement	* Work station design
* = In existing 'Manufacturing Systems' course ** = In a prior and prerequisite 'Engineering Management' course	

It was clear that only a selection of these topics could be covered in the time available — one semester. Selecting the topics to be included in the course involved much debate and there are probably as many opinions about what should be included and what should be left out as there are manufacturing engineers. Note that 'non-engineering' specific topics such as communication and negotiation skills were not included in the list as students attend specialist courses in these topics in their degree studies. However, the proposed intervention was to be designed to assist in the development of these skills,

wherever possible, by the use of team-based tasks and the production by students, of engineering reports and recommendations in an authentic context and format.

To go about the task of selecting course topics systematically, the items on the list above were first classified into five logically connected groups. The groups themselves were designed to represent sub-sets of the total activities of a manufacturing system. They were created to form a continuum of activities from an initial production layout of the plant and its equipment through to the despatch to customers of completed products.

The first pass through this process resulted in the following list of topics and groups:

Group 1. Facilities, Product and Layout Planning: product design for manufacture; facility layout; project management; automation systems; factory networks; data collection; management information systems; industrial data buses; materials handling.

Group 2. Work Standards and Facilities: work station design; work standards and measurement; learning curves; job design and work measurement; ergonomics.

Group 3. Day-to-day System Operations: capacity planning (make or buy); forecasting; line balancing; inventory management; aggregate planning; finite resource scheduling; Kanban; Materials Requirements Planning (MRP) and Enterprise Resource planning (ERP); Just-in-time (JIT) and lean manufacturing; e-commerce; supply chain management; quality operations and the customer; Statistical Quality Control (SQC), quality management, Quality Control (QC), and Total Quality Management (TQM); reliability.

Group 4. Enterprise Modelling, Simulation and Queuing Theory: Modelling manufacturing systems and simulation; queuing theory; linear programming and transportation models.

Group 5. CAD/CAM: Computer Numerical Control (CNC) programming; Computer aided Design (CAD)/Computer Aided Part Programming (CAPP) integration.

This grouping was next processed to determine the final selection of topics and each group was examined to identify any overlaps in the items listed. For example, three of the topics suggested by contributors; factory networks, data collection and industrial data buses, if merged into one topic would eliminate the repetition of a substantial amount of common material. Topics were also reviewed to identify those that might be

currently taught in other undergraduate degree courses such as the prerequisite prior course — ‘Engineering Management’. Finally, items were identified that were not considered ‘core’ manufacturing systems topics, e.g. e-commerce. Items identified in this process were merged with others or removed from the list. However, care was taken to ensure that no major ‘gaps’ in the coverage of manufacturing systems were evident and that the remaining topics were capable of being assembled into a syllabus in a fashion which made logical and technical sense.

Following this paring process, and after further discussions with the Manufacturing Systems Group, the following syllabus was prepared:

Group 1. Facilities, Product and Layout Planning: facilities and layout planning; MIS; automation; data collection and networks; material handling; low-cost automation.

Group 2. Work Standards and Facilities: work standards; work station design; job design; ergonomics.

Group 3. Day-to-day System Operations: capacity planning; line balancing; inventory management; aggregate planning; MRP & ERP; JIT & lean manufacturing; reliability.

Group 4. Enterprise Modelling, Simulation and Queuing Theory: enterprise modelling; simulation and queuing theory; linear programming.

Group 5. CAD/CAM: CNC programming; CAD/CAPP integration.

An estimate of the time required to satisfactorily present these topics was made in order to ensure that the pace of the course was not going to be adversely forced by the syllabus. The conclusion was that the material could be covered satisfactorily in the time available. It can be noted that these groupings were for design and administrative purposes only. These divisions were not described in any student documentation or teaching materials. To do so would have been acting against a major goal of the study, i.e. the achievement of a greater awareness by students of the integrated nature of manufacturing systems.

4.2.1.2. Task selection

The next step in the analysis process was to determine the number, content and format of the tasks to be completed by students in order to practice and reinforce the topics. These tasks were to be designed to be presented to students in a manner typical of

workplace assignments. The tasks were to be capable of multiple solutions and some were to require the use of small teams and the application of intra-team negotiation skills in their solution in order to initiate collaboration and reflection. In this context, reflection refers to the process of comparing what one has done with the way others have carried out the same task and, perhaps, to replay in one's mind a vision of what *should* have occurred. Where required the tasks were to make use of industry standard software tools for authenticity rather than in-house produced programs. Note that the term 'tasks' is generally used in this study and in the intervention to describe student exercises or assessments as it is more appropriate for the workplace 'feel' or environment that the intervention was designed to foster.

The outcomes of the tasks, a satisfactory design for the production line or a schedule to ensure on time delivery of orders to customers, etc., are closely aligned with the artefacts which a practising manufacturing engineer would be expected to deliver. This is in contrast to much of the problem solving carried out by students in their degree which, whilst they may solve problems in the abstract, are not referenced to any particular outcome that would serve the customer or client (Trevelyan, 2008).

Tasks that are ill-defined and have indeterminate outcomes can cause problems for students and if students are given too much leeway or freedom there is a danger that they may not achieve the learning objectives that are set. For this reason, although the tasks will not be fully defined, what information is available will be given at once, and unambiguously, in a typical company communications format. The output required from students is made clear even though the actual quantitative value or the recommendation for action may vary.

In designing the indeterminate problems an initial structure or scenario for the problem concerned was conceived so as to be situated, validly, within the overall virtual enterprise narrative. The data to be utilised in the problem was to be consistent with any enterprise data previously created and with data yet to come. For example the yearly sales target for the virtual enterprise, which is an element of one of the tasks, must be consistent with the achievable output of the designed manufacturing system, which itself is based upon the production rates achievable by the machines and operators, which in turn are a function of the machines used and the factory layout. Thus, the data

set used for the tasks is a complex web of interconnected data, facts, figures and systems. The problems must be naturally embedded in the narrative and they will exist because of the particular circumstances at any point in the progress of the story.

For indeterminate problems the students must frame the problem cognitively, assess different solutions, select a likely ‘good’ solution and be able to justify the selection. The tasks cannot be solved by applying a constrained set of rules such as might be used to complete a text book or examination question and most tasks will utilise heuristic methods. The constraints within the solution, time and cost for example, may be explicit in the data available to the students or implicit in data from earlier tasks.

It was determined that there should be one task for each of the five topic groupings. One task, that for computer controlled machining (CNC) was already in existence and a prototype ergonomics exercise was already under construction when this research began (Seidel and Sitha, 1999, Sitha, 1998). The proposed new tasks were to be introduced serially as the design of the intervention was refined and feedback from the data collection programme was analysed.

Table 4-3: Virtual Enterprise Tasks

Task	Relevant Topics	Iteration Introduced
1. Resolve Ergonomics Issues.	Work standards, work station design, job design, ergonomics.	Pilot Design
2. Layout new production facility.	Facilities and layout planning, MIS, automation, data collection and networks, material handling, low-cost automation.	Iteration 1
3. Part A, Build model of a ‘push’ production line and simulate production flow.	Enterprise modelling, simulation and queuing theory, linear programming.	Iteration 1
3. Part B, Model and simulate ‘pull’ production system.	JIT & lean manufacturing, reliability.	Iteration 2
4. Schedule production with finite resources.	Capacity planning, line balancing, inventory management, aggregate planning, MRP & ERP.	Iteration 3
5. Produce CNC code for part machining	CNC programming, CAD/CAM/CAPP integration.	Existing Task

The tasks follow a logical sequence or flow both in engineering and chronological terms and in fact may be viewed as one large, single, manufacturing system activity. This characteristic meets the requirement of situated learning theory, i.e. that tasks provide a complex and sustained learning environment (Herrington, 2006: 3164-3173), as reviewed in Chapter 2, Section 2.5.11. Barab (2000: 37-62) points out that authenticity is provided by the dynamic interactions amongst all the components [of the virtual enterprise] and that, “authenticity is manifest in the flow itself....and not in any one feature in isolation.”

For each task the sequence of presentation of the teaching materials and multimedia components were laid out in a manner that would ensure continuity in the flow of information (Gagné, 1970), as reviewed in Chapter 2, Section 2.5.9, and a template or checklist was produced to assist in ensuring a complete and consistent design and to form the basis of the methodology output of this research study. The template was used to check that all the elements of situated learning theory (Chapter 2, Section 2.5.11) were present in the design. The template also provided for recording the application of appropriate learning theory; behaviourist, cognitive and constructivist and for recording the levels of Bloom’s taxonomy (Chapter 2, Section 2.5.9) designed to be present at each stage in the task or topic. The template was also expected to be of use, post-implementation, as an aid to diagnosis should some feature of the intervention prove to be unsatisfactory.

A close correspondence was noted between the elements of the situated learning framework adopted for the intervention and a number of Gagné’s events of instruction as modified by Gunter and Kenny (2006), described in Chapter 2, Section 2.5.9. These events are repeated below:

- a) Scenario exposition.
- b) Problem setup.
- c) Reference to previous task (if present).
- d) Emphasis on relevance.
- e) Provision of direction.
- f) Elicitation of action/decision.
- g) Recording of discernable outcome.
- h) Provision of task feedback.
- i) De-briefing.

These events were added to the Task Design template shown below, Table 4-4, and are shown within brackets below the corresponding situated learning element. The example shown is for the first task.

Table 4-4: Task Design Template/Checklist

Situated learning framework Gagné (Gunter & Kenny Events)	Activity	
Authentic context (Scenario exposition)	Team Detectors opening new site to produce smoke detectors for the Australasian market	
Enable use of tacit knowledge (Refer to previous task)	N/A for first task	
Authentic content (Emphasis on relevance/challenge)	Lay out site to meet inter-department location restrictions and Production Engineer's specifications.	
Multiple roles and perspectives	Views of Factory Manager re efficiency, views of Production Engineer re output, views of staff re. safe working conditions.	
Collegial collaboration (Elicitation of action/decision)	Discuss and critique individual solutions, negotiate a common 'best' solution for submission.	
Provide expert help Provide coaching (Provision of direction)	Help from lecturer and from virtual staff at Team Detectors.	
Integrated assessment (Provision of task feedback) (Record discernable outcome)	Individual task marked promptly. Marked on meeting specifications, quality of own decisions and on suitability for use in next task (production line simulation), and on quality of team discussion, negotiations and submission.	
Articulation with other courses/topics (Reference to previous task)	No previous task. Layout to be used as a basis for next task (production line simulation).	
Promote reflection (De-briefing)	Class discussion regarding the task, the data supplied and quality/range/practicality of solutions.	
Theories of learning	Behaviourism	Information on types of production and therefore corresponding types of layout. Industry standard systematic methods of layout design.
	Cognitive	Compare various systemic methods. Select appropriate method and complete exercises.
	Constructivist	Complete Team Detectors plant layout task.
Bloom's Cognitive Domain Levels	Knowledge	Selects an appropriate systematic plant layout methodology.
	Comprehension	Distinguishes the issues influencing a plant layout design.
	Application	Applies Muther's systematic layout procedure to a closed-ended problem.

	Analysis	Identifies good and poor practice in plant and equipment layouts.
	Synthesis	Complete Plant Layout task from indeterminate data and instructions
	Evaluation	Evaluate, discuss and select the most effective solution in negotiation with team.

The following sections describe briefly the activities carried out in the design, development, implementation and evaluation stages of the methodology. A more detailed description of the evolution of the intervention's design through its several iterations is given in Sections 4.3 through to 4.7.

The elements in the design stage below and stages three, four and five of the methodology were repeated, as required, in each 'design, implement and evaluate cycle' of intervention iterations.

4.2.2. Stage 2: Design

The learning objectives for each topic and associated task were prepared. A sample of some of the learning objectives for the topic of plant layout are shown in the design template in Table 4-4. The design incorporated the elements of the situated learning framework as set out in Chapter 2, Section 2.5.11.

The other design activities required were the development of the immersive narrative and the user interface – the company's web pages, realia and documentation.

The aim was to create a creditable and detailed narrative concerning the virtual enterprise which would form the scenario to which all teaching materials would be referenced and within which all student tasks would take place. The initial version of the narrative was limited but became much more comprehensive with each succeeding iteration, with the addition of new products, new tasks, corporate documentation and further multimedia material. This evolving narrative is described in the sections detailing the individual design iterations. The most important consideration was to design the narrative such that it would satisfactorily accommodate the student tasks that were planned and that the tasks should arise naturally from the narrative.

With the basic narrative for the scenario prepared, that of a medium-sized manufacturing company producing safety products, the look-and-feel of the virtual enterprise's company website and documentation was decided upon.

4.2.3. Stage 3: Development

The development of the intervention was carried out topic group by topic group and a similar procedure was followed for each, as follows:

- The relevant topic teaching material was prepared.
- The relevant multimedia assets were collected or created.
- The relevant professional software applications were installed and tested.
- Tutorials were written to introduce students to the software.
- The topic materials and presentation were crafted to fit logically into the overall narrative scenario of the virtual enterprise.
- Materials for the student tasks and their assessment were created.
- The web site for the virtual enterprise was amended as required.

This sequence was adopted, with modification where necessary, for each iteration.

4.2.4. Stage 4: Implementation

In this phase the website was loaded on to a network server and checked for broken links, misplaced graphic elements, etc. The intervention was then made available to the students on the manufacturing systems course. Observations were made of student experiences with the environment and minor bugs and errors were corrected. A table recording the progress of the design over several iterations is shown overleaf, Table 4-5.

Table 4-5: Virtual Enterprise, Record of Iterations

Version	Virtual Enterprise	Features	Available Tasks	Data Collection
Pilot	INFOStation	Ergonomics (ErgoEASE®).	Ergonomics task.	Questionnaire Observation.
Iteration 1	INFOStation	New departments added to expanded web site. Simulation facility added (Arena®). e-library facility removed.	Ergonomics task. Plant layout task. Model & simulate 'push' production task.	Group interviews. Observation.
Iteration 2	Team Detectors Ltd.	Enterprise given new name and identity. Web site redesigned using CSS. Web site hosted by external ISP.	As above.	Observation. Student interviews.
Iteration 3	Team Detectors Ltd.	Added finite planning and scheduling facility (Preactor®). New products added – DEEP and GAMP. Company Asset register completed. Bills-of-Materials added.	As above plus: Production scheduling task. Model & simulate 'pull' production task.	Observation. Pilot run of LSI and LEP
Iteration 4	Team Detectors Ltd.	Full financial and resources database and other realia added. Interactive BOM added. Company profile published. 3D model added.	As above.	Student Questionnaire. Interviews. Observation. LEP LSI x 2

In order to facilitate the learning process students were encouraged to read about the important concepts of the topic in question before the lecture session. Students were provided with a schedule of the topics to be covered and the teaching material was made available on the university document management system (CECIL) for reading or download. The lecture sessions reviewed the material and discussion took place, with examples, about its application in the workplace. Discussion of the practical problems in applying manufacturing system design and management techniques was encouraged utilising, where appropriate, students' shared experiences from their own industrial placements. The classroom discussion will create an environment where students are able to share their placement experiences and learn from each other.

4.2.5. Stage 5: Evaluation

In this phase, post delivery, evaluation of the effectiveness of the intervention and its reception by students was carried out (as described later in this chapter in Sections 4.3 through to 4.7). Additions and changes to the overall concept, and to details of the learning materials, were made as necessary. Details of the feedback and evaluation data collected for each iteration are set out, with analysis, in Chapter 5.

A defining characteristic of design-based research is a rich, or thick, record of the iterations of the cycle of design, application, assessment, reflection and modification and thus the following sections describe the application and development of the interventions in detail.

4.3. Pilot Design

The pilot design version of the intervention, combining web-based and textual material, was based upon a fictional engineering manufacturing company—‘INFOstation Limited’ (Seidel, 2001: 415-416) and (McCarthy et al., 2002). INFOstation was manifested as a web site on the Mechanical Engineering Department’s web server and contained four simulated departments: Design Office; Planning Office; Quality Assurance Laboratory; and Administration.

In this initial concept the virtual factory included links to web pages containing additional reading (supplementary to the hard-copy course notes) for each major topic in the manufacturing systems course – hence the name ‘INFOstation’.

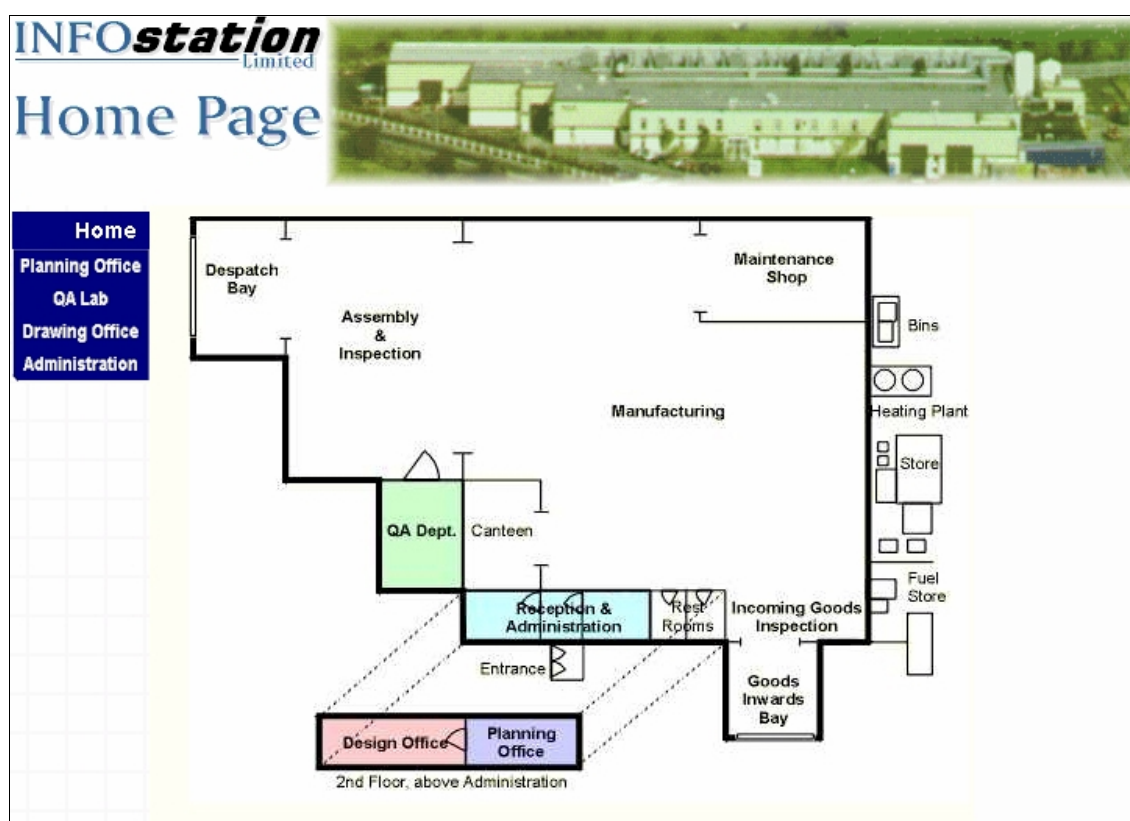


Figure 4-1: Intervention Web Site, Pilot Design

4.3.6. The Task – Ergonomics

For this pilot intervention the topic of ergonomics was selected, from the manufacturing systems course syllabus, to be the focus of the multimedia delivery and the subject of a student task. The field of ergonomics was chosen because it is firmly focused on the people and human factors within an organisation and it was believed that this would provide additional motivation for the students to become engaged with the concept. Everyone, at one time or another has obtained first-hand knowledge of an ergonomics issue via an uncomfortable chair, poor posture at a desk or workstation, etc. In addition the subject was a good candidate for the use of additional forms of media such as video clips of an ergonomically suspect material handling operation, online anthropomorphic data sheets, and professional level ergonomics software—ErgoEASE®.

The students were told, through the medium of the company's on-line 'Staff Manual', that the Planning Office was responsible for the efficient planning, maintenance and review of the handling, assembly and machining tasks within the organisation. This responsibility included ensuring that the staff were not required to carry out tasks that

might be dangerous, excessively tiring, or detrimental to their health. In order to meet this responsibility the planning office staff were to be familiar with the theory and practice of ergonomics.

Students were informed by e-mail that as an engineering cadet at the company they had been allocated to the planning department and that as a result they were the recipients of a memorandum from their 'employer', in the person of the manufacturing manager. The memorandum requested them to immediately complete an ergonomic investigation into a handling operation that was causing some concern to both the employees and their union.

In order to make the scenario more realistic several videos shot earlier at a local manufacturing company were utilised. The scenes recorded were of material handling operations which appeared to involve poor ergonomic design and physiological stress on the operator. The video clip selected for the assignment was the one which recorded the longest and most complex series of movements by the employee. This was also the operation which was the most troubling from an ergonomic point of view.

In the task under investigation the operator removed packs of cans from a pallet, placed them on a conveyor bench, and then unbundled them. The total job cycle included removing the packs from a six-layer-high stack on a pallet. Some vertical reaches were at eye height whilst the lowest layer was almost at floor level. Since the packs were three deep across the pallet, the task also involved different severities of horizontal reaches. In industry the analysis of this task would cover the unstacking of the complete pallet load to enable an investigation of the total severity of the task and an estimate of the total energy required to unstack the complete pallet. For this task, however, the students were asked to analyse only the most severe motions for the operator during the task. The objectives of this exercise from a technical point of view were:

- To make students aware of ergonomic issues in the workplace.
- To reinforce and extend the material covered in lectures.
- To obtain some hands-on experience in industrial problem solving and productivity improvement.
- To give students practice in learning and working with professional computer-based analysis tools.
- To practice the important skills of professional communication and report writing.

From a pedagogical point of view the exercise was to:

- Initiate immersion in the intervention, using a ‘personal’ operator’s story,
- To present an indeterminate problem with multiple answers (there were many ways to analyse the task and even more re-design options).
- To present an ill-defined problem (students had to estimate some of the task parameters and estimate costs for any re-design).
- To present a problem they could view from different perspectives. That of themselves (the manufacturing systems engineer), that of the operator, of the company management and of the union.

Students were asked to view the video clip of the operation (see Figure 4-2) located on a page in the company’s Web site and to view some data collected by an earlier ‘investigator/employee’, which was also located on the site. This data included the length of a shift, the body weight of the operator, the weight of the load being handled, wage rates, etc.



Figure 4-2: A Still Clip from the Video

4.3.7. The Tools – ErgoEASE®

Students used a professional software package, ErgoEASE®, to perform the ergonomic analysis. The program which uses a graphical interface (see Figure 4-3) allows students to input the results of a detailed movement and posture analysis together with general task parameters (e.g. task cycle time), to analyse the operation and produce a range of

reports on the ergonomic safety of the operation. The energy expended, skeletal and muscle stress, etc., can then be examined.

Figure 4-3: A Screen Capture from the ErgoEASE® Program

4.3.8. Narrative

The text of the memorandum to the students was:

Please complete an ergonomic investigation into a two-phase handling operation.

Analyse the work cycle shown in the video clip including the initial and final reaching and lifting operations. Utilise anthropometric tables to estimate values and dimensions not given. I would like you to write a detailed narrative of the video clip. Then, enter the Handling and Motion sub-elements into our ErgoEASE® program from your narrative and carry out an ergonomic analysis. In your report to me I would like you to:

- a) Calculate the Maximum Kilo Calorie Rate/Minute (from your ErgoEASE® results).

- b) Comment on the ergonomic relevance of the particular lifting cycle you have analysed in the context of the total task of unloading the pallet.
 - c) Complete a Rapid Upper Limb Assessment (RULA) analysis on what you regard as the two most ergonomically sensitive parts of the cycle.
 - d) If you believe it necessary, redesign the work station, with costings, to eliminate any ergonomic issues.
 - e) Recommend a suitable illumination level for the workspace.
- Regards,
Manufacturing Manager.

It was suggested to students that as a competent INFOstation employee their recommended solution should consider all the usual, relevant industrial issues and constraints, e.g. costings, effectiveness of solution, cost-benefit analysis, pay-back period, downtime, likelihood of staff and union acceptance, etc.

4.3.9. Evaluation

Following completion of the ergonomics assignment the students were surveyed by questionnaire to discover what they felt about the use of the INFOstation immersive scenario and whether, or not, they felt that it was an improvement on more conventional delivery systems. The survey instrument, a Likert scale (as described in Chapter 3, Section 3.4.4.1) was developed in conjunction with the University's Centre for Professional Development and consisted of eight questions (see Appendix E). Four of the questions were concerned with the design of the INFOstation interface whilst the other questions dealt more broadly with the virtual factory concept and whether or not it should be extended to assist in the delivery of other topics. A pilot run of the questionnaire was carried out with 10 students to ensure that the questions were clear and unambiguous.

A randomly selected sample of 60 students was asked to complete the survey and 51 accepted. The students were chosen by allocating each class member a random number (utilising the random number generator in Microsoft Excel) then sorting the random numbers in ascending order and selecting the first 60 in the list.

Students were asked to indicate their opinion of a number of factors on a five-point Likert scale from 'Strongly Agree' through to 'Strongly Disagree'. See the questionnaire form in Appendix E.

4.4. Intervention – Iteration One

As a result of the information gained from student evaluations of the first application of the intervention, the second version of the virtual enterprise was substantially re-designed. The style of the web site was made more contemporary, additional pages were added and the virtual organisation moved to more up-market virtual premises. See Figure 4-4.



Figure 4-4: INFOstation's Revised Web Site

The research programme now focused upon increasing the reality of the virtual enterprise. The pilot design had not emphasised the virtual products manufactured in the organisation or used their characteristics to increase the probity of the scheme. The opportunity was taken to carefully select a product range for the re-vamped organisation. The products chosen had to be consistent with the company's New Zealand location and likely markets. For example the choice of auto manufacturing would be inappropriate because of a lack of supporting industries, the small New Zealand domestic market and distance from export markets. A modern mass

manufactured product was thus ruled out of consideration. The following factors were considered essential to achieve fidelity:

- A product range which would be manufactured in small to medium quantities.
- Products that would have a ready market both in New Zealand and Australia.
- Complex products that would have some intrinsic interest.

Features regarded as desirable to increase the flexibility and range of the intervention were:

- Products that would incorporate modern technologies.
- Products that would require a range of engineering disciplines in their design.
- Products that would require a broad spectrum of manufacturing technologies to manufacture.

After examining and discarding a number of alternatives it was decided that the virtual company would manufacture a range of fire protection equipment. In particular it would manufacture smoke and inflammable gas detectors and fire suppressant systems (excluding sprinkler systems). The smoke detection and suppressant systems to be manufactured were to be unique in design and targeted at commercial and industrial users. This range of products seemed to meet the fidelity specification for the intervention described above.

Utilising a unique design meant that a reasonable volume of sales could be justified even in the relatively small Australasian market. Also, the product would not be in competition with any equipment currently manufactured by major potential competitor companies such as Chubb, Wormald or Firefighting Enterprises Limited.

The products also met the specification requirements for flexibility since they incorporated the application of a range of engineering topics, such as pneumatics, control systems, electronics, thermodynamics, and required a mixture of design disciplines including mechanical, electrical and electronic, and a varied range of manufacturing methods to produce.

Discussions with students, and the investigator's observations during the ErgoEASE® computer laboratory sessions, had shown that they rarely, if ever, used the hyperlinks on

the web site to access the supplementary topic material available in the INFOstation company 'library'. Students indicated that they felt that they had all they needed as far as material was concerned in their class notes and, in any event, if they needed more they preferred to use Internet search engines which offered greater topic scope and improved search functionality. In addition, they felt that this dual functionality in INFOstation – the presentation of 'workplace situated' problems in conjunction with a 'university situated' topic library – sent mixed messages about the virtual organisation and detracted from its reality. As a result the topic library functionality was discarded for this, and later, iterations. Supplementary topic material was placed on the university course document management system to divorce it from the virtual enterprise scenario.

The first iteration of the intervention built on the existing virtual enterprise structure and its ergonomics assignment with the addition of further functionality. The additions were designed to reinforce material taught in the manufacturing systems course on the topics of factory layout and process simulation. The goal was to deliver these topics, via the virtual enterprise, in a way which, it was expected, would promote a less dualistic and more relativistic mode of thinking and analysis by students (see Chapter 2, Section 2.7.16). In laying out a factory, or department, in particular there are often many workable or acceptable solutions and rarely one, right, answer.

In the evaluation of the course there had been some criticism of the ErgoEASE® software. A minority of the students had been unhappy with the program. The most relevant issue here was the fact that the version available to students was not designed to run over a network as it was required to do in the INFOstation application. As a result the program would occasionally shut down, or freeze intermittently, and students would lose their work. Often backups would not open satisfactorily. As a result the decision was taken, following discussions with the faculty's IT staff, to load the software onto individual computer workstations in the laboratory for future iterations.

4.4.10. The Tasks – Plant Layout, Modelling & Simulation

4.4.10.1. Plant layout

Students received an instruction from INFOstation Limited to visit the company's web site to learn details of a proposed move to a new factory, and to view a plan of the new site and the new, empty, building. Also on the web site was a report by the company's

managers describing the departments which were to be re-located, their function, approximate floor area, and any co-location restraints between them. This report had some inconsistencies deliberately included to ensure that the co-location requirements could not be met in total without compromises. To increase the level of ill-definition the positions of some departments on the site were implied by their function rather than being explicitly stated. For example, it was hoped that the students would, without direction, place the Goods Inwards and Despatch departments in such way that they had frontage onto the access road and that the visitor reception area would be placed the front of the site close to the main highway. The students were expected to use a formal methodology such as Muther's (1955) Systematic Layout planning (SLP) to analyse and best meet the co-location requirements. Demonstrations of Muther's and other systematic methods of optimising facilities layout had been introduced to the students in formal lectures. The pedagogical framework of situated learning adopted for this study emphasises the support of the collaborative construction of knowledge. To meet this requirement the students were allocated to three-person teams whose responsibility was to meet as a design team (in tutorial time), discuss each member's solution and negotiate a joint 'best' solution utilising whichever features from individual submissions they chose. A similar collaborative procedure was required for later tasks—'Production Scheduling' and 'Production Line 'Pull' Simulation'.

4.4.10.2. Production line modelling and simulation

INFOstation's management also required students to simulate likely production flows within their planned new layout. Students were given details of a smoke detection product, its manufacturing process, the departments it was processed in, the machinery and staffing available for production and a target production rate. In order to supply a report to the company, the students were required to build a model of the plant, based upon their earlier plant layout solution and simulate the machine production rate, waiting times, queue lengths and inspection stations utilising the modelling and simulation software package—Arena® from Rockwell Software Inc.

Travel times from department to department, on an overhead conveyor, were calculated utilising the centre-to-centre distance between departments which students had obtained from their layout task described earlier. Poor solutions to the plant layout task would have an impact in producing less than optimum process times. Students had been

introduced to simulation techniques and the use of Arena® software in lectures and tutorials. The students were required to analyse production flows and discover if there were any production bottlenecks. They were then to advise the company if the required production target could be met by their proposed layout, its equipment and staffing levels. If, in their opinion it could not, they were to make justifiable recommendations for changes to parameters such as staffing levels, number of shifts, material handling equipment, etc.

4.4.11. Tools – Visio® and Arena®

To complete their plant layout task, students needed to draw the site and building in plan, marking the boundaries and location of the departments within the building. They were also required to find the approximate geometric centre of each department as an aid to calculating product movement distances from department to department for the next stage of the assignment. For these tasks students were recommended to use the graphics and charting software Visio®. This would facilitate the examination of a number of alternative layouts as the program provides the ability to easily draw the department outlines and drag them around the screen in various configurations. It also provided 'sticky', dimensioned, connections between the centres of departments.

For the production line model and simulation task students were introduced to the professional simulation software, Arena®. This program, based upon the SIMAN simulation language, allows the user to build models of manufacturing systems using a library of standard flow chart symbols (modules) which may be dragged into position on the screen and connected together logically to represent the physical hardware on the shop-floor and the flow of product. The modules are then configured with the parameters of the machine, inspection station, conveyer, etc. they represent. The parameters can include information such as production rate, power consumption, cost/hour, breakdown rates, etc.

The Arena® program is a discrete-event simulator which simulates the behaviour of entities when an event occurs at a distinct moment in time. An entity is a component of the system and may be a machine, an inspector, a conveyor, storage tank, etc. An event is a change in state of the system, e.g. the arrival or departure of a customer or part, the completion of a machining or inspection operation, a machine breakdown, etc. Once the

model is built the production process can be simulated with various parameters such as shift lengths, working hours per week, etc.

4.4.12. Narrative

The following extracts are from the material presented to the students to set up the scenario for the assignment. The first (a) is from the introductory narrative presented to students and the second (b) outlines the tasks required of the student by the company. The third extract (c) is part of the data sheet describing the planned process flow for the product, a smoke detection device.

a) “You are asked to determine an efficient layout for the manufacturing and other activities which will be accommodated in the area and to simulate some of these manufacturing operations based on an ARENA® model (see the document ‘Outline of Main PCB production processes and times’). The data from your simulation will be used to obtain an estimate of the total time the main PCB for the smoke detection unit will spend in the system and to assess the likelihood of serious bottlenecks forming in the process.”

b) “The chart attached (Activity Relationships) shows the estimated activity relationships between the activities and services that will be operating in the new area. Using Muther’s systematic layout planning procedure, draw a relationship diagram from this data and, using the details of the amount of space to be assigned to each activity (see web page), draw a space relationship diagram and draw a departmental layout on the building plan.”

“Build an Arena® model of the manufacturing operations for the following four departments only: PCB Manufacture, PCB Assembly, Resin Encapsulation and Final Assembly”

“Note: To calculate the inter-departmental transfer times, assume that the products moving between departments will be conveyed by a continuous loop overhead conveyor travelling at 5m/minute. The transfer ‘delay’ within your model should be set to your estimated transfer times on this conveyor. Assume that, on average, parts move on the conveyor from, and to, the departments’ geometric centres as measured on your proposed layout.”

c) “PCB Manufacturing Department: Cut-to-size and notched printed circuit board blanks will be produced by an outside supplier (outside the bounds of this model) and, as a result of using a planned just-in-time supply strategy, we expect to have batches of four PCB blanks arriving into the PCB Manufacturing Department every 40 minutes. Upon arrival they will be transferred, singly, to the PCB Etching and Drilling Machine. The process time on this machine is expected to have a minimum value of 5 minutes a maximum of 12 and a most likely time of 8 minutes. Parts leaving this operation will be transferred to the Lacquer Applicator & Drying Oven with a constant 20 minutes process time. On leaving this machine, parts will move to an inspection station where the time taken to complete inspection will probably have a minimum time of 6 minutes a maximum of 15 and a most likely inspection time of 9 minutes. It is expected that 95% of printed circuit boards will pass inspection. Parts failing inspection will be scrapped. Parts which pass will be routed to the PCB Assembly Department”

A screen shot of a typical solution to the simulation task is shown in Figure 4-5 below.

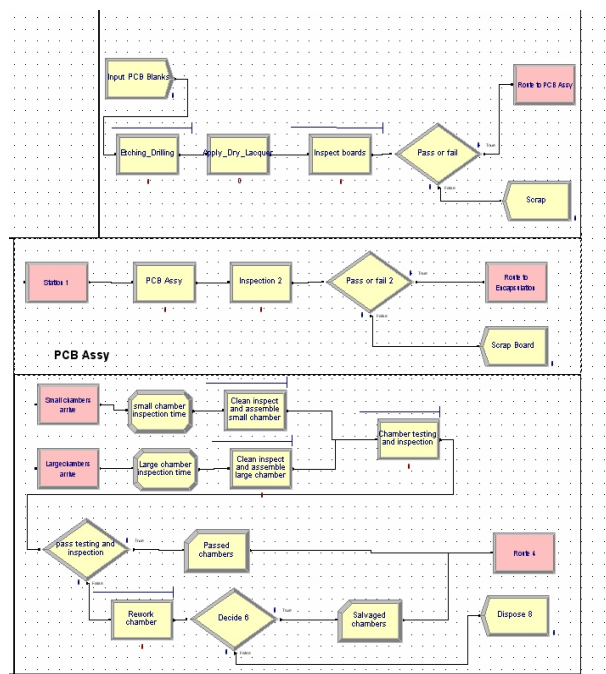


Figure 4-5: Typical Solution to Simulation Task

4.5. Iteration Two

For iteration two the opportunity was taken to select a new name for the organisation more aligned with a ‘real’ company’s trading name—the name selected was ‘Team Detectors Limited’. This was chosen as it was short and memorable, indicated the company’s area of operations and also alluded to the virtual company’s strength—its coherent design and manufacturing teamwork which, it was hoped, would also be demonstrated by the students when they attacked the problems that Team Detectors Limited would present to them. A more typical ‘industrial’ site and building was also chosen for the enterprise which was to be more consistent with the site plan and building structure in the plant layout scenario.



Figure 4-6: Team Detectors Limited - Auckland Premises

With a new name and a valid product range established, the opportunity was taken to re-design the organisation’s web site. The HTML code which contained both the textual and graphics content of the site, and its styling code, was replaced by semantic XHTML compliant coding with the formatting and styling specifications contained in separate cascading style sheets (CSS). This change was carried out to conform to the latest in web coding practice and its emphasis on strict mark-up coding and semantic layouts. The change was expected to make the site easier to expand and troubleshoot.

A major change in the web site was a change in content. The earlier INFOStation versions of the concept had, because of their focus on the task to be done by the student (e.g. improve ergonomics conditions), consisted of web pages describing the various

departments in the company, their function and responsibilities. The new version was substantially different and conformed more closely to a commercial company's site format with a focus in the product, marketing services and information for customers rather than internal company organisational matters.

Although it had not been mentioned specifically by students in conversation, or interviews, it seemed to be an anomaly for an organisation which was supposedly an active business enterprise to have a URL containing the web address of the University of Auckland. To remove this inconsistency the domain name 'teamdetectors.co.nz' was registered with the NZ domain name registry and a site with this URL was hosted on a server located at a commercial internet provider — IHUG. To increase the validity of the organisation further, external email accounts were set up in the names of several virtual members of the Team Detectors management team.

The information from the web site that was required by students to attempt the tasks was commercially sensitive information and would not normally be available for access by customers or casual site visitors. To eliminate this anomaly a special secure section of the site was set aside for engineering students/company cadets which could only be accessed by University of Auckland students in possession of the correct password.

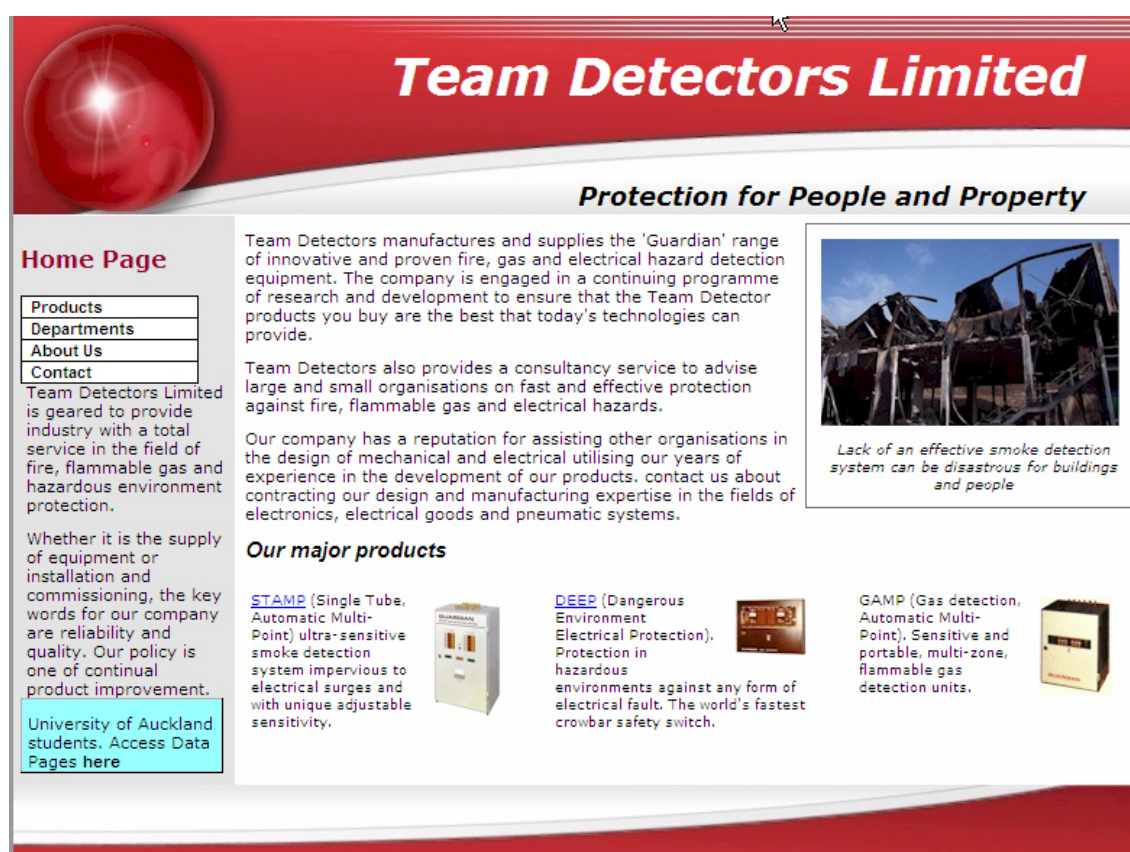


Figure 4-7: Team Detectors Limited – Website, Home Page

4.5.13. Evaluation

Following the application of the second iteration of the intervention a randomly chosen sample of 12 students (from a class of 65) were interviewed as a group to discover what they thought about the use of the Team Detector Limited scenario. The students were selected following a randomisation process, as previously described in Section 4.3.9. The interview was designed to prompt the students to talk freely about the intervention and to consider whether, or not, they thought the experience had made it easier to deal with any ill-defined and open-ended problems they might be confronted with in the future. They were also asked if they felt the virtual enterprise concept was worth continuing with in future courses.

4.6. Intervention - Iteration 3

The next iteration of the virtual enterprise intervention was expanded to include another major topic in the manufacturing systems course. Having already covered the topics of plant layout, and production flow simulation within Team Detectors Limited, the

immersive scenario was expanded to include manufacturing production planning and scheduling.

In order to add the planning and scheduling function to the virtual enterprise a comprehensive portfolio of background data was evolved, expanding considerably upon the existing data set, to give further verisimilitude to the organisation.

This data set consisted of the following:

- A complete inventory of all the capital equipment available to Team Detectors Limited. This contained details of the equipment, its size, age, purchase price and current depreciated value, machine charge-out rate per hour and power requirements.
- A list of the major employees in the company and a summary of the number of other employees by occupation. This list also included employee salary and wage-rate details to assist with production cost calculations.
- A customer data-base and contact list containing all of the company's past and present customers.
- A current order book.
- Bills-of-materials for each of the company's products.
- Process sheets for each of the company's products.

Also in this iteration, pilot applications were made of two investigative instruments—The Kolb Learning Style Inventory, Version 3.1 and the Learning Environment Preferences (LEP) instrument which were referred to in Chapter 2, Section 2.7.15, and described in detail in Chapter 3, Section 3.4.4.4.

4.6.14. The Task – Finite Capacity Scheduling & Lean Manufacturing

The new task in this iteration was that of finite capacity scheduling. This required students to schedule a numbers of orders through the Team Detectors plant in such a way that the required delivery dates were met.

Finite capacity scheduling is a process whereby a production plan, consisting of a sequence of operations to fulfil orders, is generated based on the real, as opposed to theoretical, capacity of resources. These resources can be machines, operators, tooling or anything that could be a constraint on the production process. The two major problems in scheduling are assigning jobs to machines or work centres and setting the sequence of jobs to be processed at a given machine or work centre. For the most part

scheduling optimisation techniques can be used only if certain assumptions are made about the system by the manufacturing engineer; assumptions which are often not borne out in practice. Scheduling manufacturing processes can be complex because of the influence of random events and variability. For example, engineers must often deal with sudden changes to the schedule (breakdowns, operator sickness, etc.), variability in the process setup and processing times, and miscellaneous interruptions. Another problem is that, for general, industrial-sized problems, there is no proven method for easily identifying which of several viable solutions is the optimum one. It is, generally speaking, unrealistic to work through a very large number of possible alternatives to identify the best one. As a result, scheduling is far from an exact science and, in many instances, is an ongoing daily or weekly updating task for a manufacturing engineer.

Computer technology can reduce the burden of scheduling and assist in finding a feasible solution. To make *real-time* scheduling possible students used Preactor[®], a popular computer based scheduling system. The students' task was to distribute the workload amongst work centres and decide which job processing sequence to use in processing customer orders. One of the virtual products to be scheduled, the ionisation chamber which ionises smoke particles passing through it, is shown below in Figure 4-8 below.

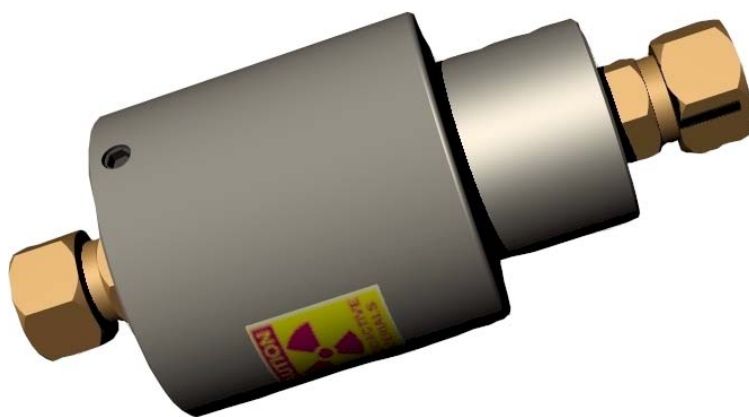


Figure 4-8: 3D Model of Virtual Product, Ion Chamber Assy.

A further, smaller, task was also added in this iteration. The students were to revisit their earlier production simulation model and re-design it to simulate the effect of changing from a 'push' manufacturing philosophy to a 'pull' philosophy with the aim of producing a leaner and more efficient manufacturing system.

Note: A ‘pull’ system manages the flow of materials and components in a manufacturing process by replacing only what has been consumed and only what is immediately deliverable to customers. This method reduces the work-in-progress, surplus inventory of raw materials and stores of finished goods. Customer orders drive the production schedules based on what is actually required rather than forecasting demand in advance and manufacturing to match forecasted demand which may, or may not, eventuate (‘push’ manufacturing).

4.6.15. The Tools

The main tool used in this expansion was a leading computer-based planning and scheduling tool – Preactor®, which is used to replace manual planning boards. To use the product the Preactor database must first be loaded with all the information required to plan and organise manufacturing schedules. This information includes details of the manufacturing equipment available and its associated machine hour costs, machine production rates, product scrap rates, and details of manufacturing shift times and holidays. Also required, of course, are details of the products to be manufactured, their process routes and process times and full details of the company’s customers, their orders and required quantities. A screenshot of the Preactor® program scheduling interface is shown in Figure 4-9 below.

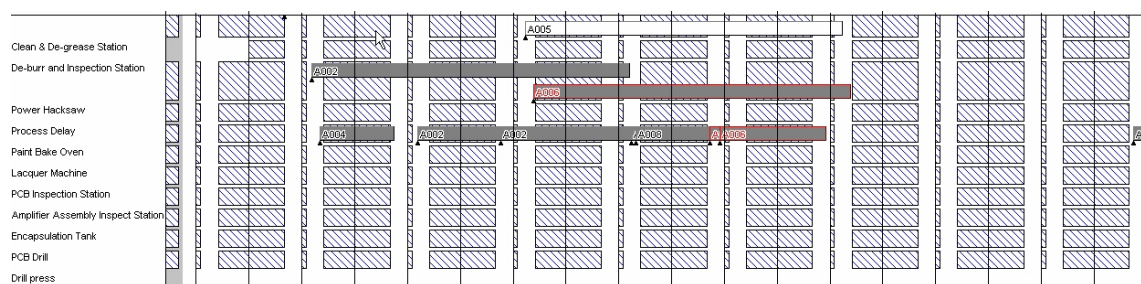


Figure 4-9: Finite Resource Scheduling Task

4.6.16. Narrative

The Preactor task was communicated to students as follows:

Hi,

I would like you to prepare a production schedule, utilising Preactor finite scheduling software, for Team Detectors Limited for Week 40 (first week in October, Monday 2nd) onwards. The orders to be scheduled are detailed on

the Team Detectors Manufacturing Schedule (No. 348) available for download on this site.

We would like to know the following:

1. Will any of the confirmed orders be late? If so which ones and what is the likely earliest date they will be finished?
2. What is the latest date at which these jobs should be started to be finished by the due date?
3. Can the quantity of the Team Detectors 'Make to Order' job be increased and still be completed by 5pm on the due date and, if so, what is the maximum quantity that can be made? Note that the quantity of items made must be a multiple of five.
4. With the Team detectors 'Make to Order' job scheduled with the maximum quantity you have determined above, can the proposed Christian Salveson Company order be completed in time? If not what is the likely earliest finish date?
5. If we replaced the resource for Op. 20 for the 'Enclosure Plate, Ventilation' with the CNC Drill resource, with a set up time of 45min and operation time of 5min, could we start the Christian Salveson order on 2nd October and meet the due date requirement? If so, what delivery date could we promise the customer?

Please save and submit your final, completed, Preactor schedule, in a folder named with your initial and surname, to the Submit Folder for MechEng 352 on the Department of Mechanical Engineering's 'S' Drive by Friday 5th October. Please also furnish, by the same date, a one page sheet (with the Task 4, Cover Sheet attached) containing in a few sentences, or a table, the answers we are seeking to the scheduling queries above.

Regards,

Chris Waller, Site Manager, Team Detectors Limited.

The Task Sheet that accompanied this memorandum was:

Having completed the design and simulation of a layout for the new Team Detectors Limited production plant you are now asked to apply a commercial finite scheduling program to the system to plan production runs.

The results of your scheduling efforts will demonstrate the interlocking and complex nature of the planning and scheduling process and give you some indication of the way in which manufacturing engineers' tools such as Preactor can save time, allow for last minute changes to production plans, and produce close to optimum schedules.

Team Detectors are now planning for production week 40 (W/B 2nd October) at the Avondale plant and have to schedule several customers' orders to begin manufacture in that week.

The company needs to know how best to schedule the jobs to meet the customers' due dates. It is assumed for the purposes of scheduling that all transfers between departments and work centres are instantaneous. It is also assumed that there are no reject items and so the number of pieces made matches exactly the number ordered (i.e. we make no allowance for additional pieces to replace out of specification items).

Details:

Full details of the task are on the Team Detectors Limited site (<http://www.teamdetectors.co.nz>). The site has a section set aside for you and in it you will find the data required for the completion of the task. To enter this section click on the link on the Home Page. The required User Name is "student" and the Password is "guardian". As outlined in the memo on the web site, and as discussed in the lecture, you may use that part of the Team Detector's database which is on the Intranet for most of the product, work-shift and resource information required.

The data-base has not yet been updated with the new process for the Amplifier, Detector which you simulated in Arena®. Details of this part's manufacturing process, and its required resources, are also on the web site and you will need to add this information to your Preactor Database.

4.6.17. Evaluation

As an aid to evaluating the intervention, students were observed interacting with the software and working upon the tasks in a series of tutorial sessions in the computer labs. The results of these observations are described in Chapter 5, Section 5.3.4.1.

4.7. Intervention - Iteration 4

No major changes were made to the format or style of the virtual enterprise web site for this version as there appeared, from the students' responses, to be no pressing requirement for it. However, considerable effort was made to increase the Team Detector's realia and presence by the addition of further graphical material. See Figure 4-10 below for an example.



Figure 4-10: Team Detector's Reception Area

An important addition to this realia was the publication of the company's profile and prospectus (See Appendix A). This full-colour document, modelled upon a typical company prospectus, contained details of the company's history, products, place in the market, senior staff and copies of the company's statutory Financial Performance and Financial Position statements. Apart from adding verisimilitude to the virtual enterprise, the purpose of the company profile was to place characters into the scenario in the form of the company's senior manufacturing and engineering staff. These people were introduced by their photograph, a short biography and contact details. By inserting

characters such as these the intervention is ‘humanised’ and expected to make the intervention more interesting to the student.

Also a list of capital equipment available for production was prepared. There were no major changes to the course or to the immersive tasks the students were asked to carry out except for some minor documentation amendments. During this iteration, following earlier pilot applications, two investigative instruments – The Kolb Learning Style Inventory, Version 3.1 and the Learning Environment Preferences (LEP) instrument were applied. These were described in detail in Chapter 3, Sections 3.4.4.4 and 3.4.5.1.

5. Data Collection & Results

5.1. Introduction

This research study examined the use of a computer-based, immersive, multimedia teaching intervention in the form of a simulated manufacturing organisation or virtual enterprise.

This chapter records the data that was obtained over four iterations and five applications of the intervention. It was collected from several sources in accordance with the principles of the design-based research methodology that was adopted for the project and described in Chapter 3. That is, information was gathered from multiple sources including student surveys and questionnaires, group and individual semi-structured interviews with students and the researcher's observations of students' interaction with, and reception of, the intervention. The data is used to assist in determining the extent to which the intervention design met its goals (specified in Chapter 1) of improving the delivery of a manufacturing systems course occupying a complex, primarily non-quantitative and ill-structured domain and of providing answers to the research questions.

The chapter also includes details of the results of surveys of students' learning styles and levels of intellectual development utilising appropriate survey instruments as reviewed in Chapter 2, Section 2.7.15, and described in Chapter 3, Section 3.4.4.4. Kolb LSI learning style surveys were carried out to determine if the designed pedagogical approach of the intervention matched the most common student learning style preferences. The Moore LEP survey was applied to determine if the student tasks in the intervention were presented with an appropriate level of indeterminacy, or 'vagueness'. An appropriate level being one which encourages students to accept, intellectually, that problems may have more than one valid answer whilst at the same time not requiring them to perform too much of a rapid intellectual leap from dualism to relativism. The

aim was to encourage students to move from positions of duality to positions of relativity. This issue was discussed in detail in Chapter 2, Section 2.7.16.1. The task formats and presentation must encourage this intellectual development but not be aimed at a relativistic position too far from the typical student's current position in order to prevent discouragement, and frustration with the ill-defined elements of the tasks.

5.2. Data Collection Programme

Several data collection techniques were employed in this research. The use of different methods to collect data allows the researcher to collect multiple perspectives on the design of the intervention and of students' perception of its utility. The use of varied techniques also assists in contributing to the credibility of the data and is a practice known as triangulation. The methods of data collection are described in detail in Chapter 3, Section 3.4.

The data was collected from course participants in five sequential, annual presentations of the Manufacturing Systems course at the University of Auckland. This course is of twelve-week's duration and is offered in the second semester to undergraduates in the third year of a four-year undergraduate degree in mechanical engineering. The data was collected from a pilot study and four further iterations, as described in Chapter 4, with the instruments described below. Information from each stage was analysed and then used to design and implement improvements to the virtual environment and to the student tasks contained within it. Details of the data collected are set-out in Section 5.3.

The data collection programme was as follows:

Year one - Pilot Design: A two-part student questionnaire and the researcher's observations were used to evaluate students' perceptions of the intervention's pilot design. The questionnaire was designed to separately evaluate (a) the intervention's virtual factory interface and (b) the assistance provided by the intervention to the students' reception of the course topics. A copy of the student questionnaire is included in Appendix E.

Year Two - Design Iteration One: Data from group, semi-structured, interviews, conducted with four groups of three students each, combined with the researcher's

observations, were used to assess students' experiences with, and impressions of, the virtual factory intervention.

Year Three - Design Iteration Two: Individual, semi-structured, interviews were conducted with students and, with the researcher's observations, were used to evaluate the students' perceptions of a revised intervention design. A copy of the individual interview structure is included in Appendix E.

Year Four - Design Iteration Three: The researcher's observations of students' reception of, and interaction with, the third iteration of the intervention's design was used to assess the effects of the major design changes made as a result of feedback from iteration number two. Kolb's Learning Style Index and Moore's Learning Environment Preferences instruments were trialled and administered to students to collect data on the distribution of student learning styles and students' positions on the Perry scale of intellectual development. Copies of these instruments are contained in Appendix E.

Year Five - Design Iteration Four: Student questionnaires, individual semi-structured interviews and researcher observations were used to assess students' reception of iteration number four. The questionnaire, a modified version of the instrument used for the pilot design, was designed to separately evaluate (a) the virtual enterprise's computer interface and (b) the learning assistance provided by the intervention. A copy of the questionnaire is included in Appendix E and a copy of the interview structure in Appendix E. Kolb's 'Learning Style Index' was completed by students, pre-course and post-course, and Moore's 'Learning Environment Preferences' instrument was also administered.

5.3. Data Collection

5.3.1. Data - Pilot Design

5.3.1.1. Student Questionnaire Structure

The purpose of each question in the Pilot Study questionnaire and its relationship to the research questions, where relevant, are set out in Table 5-1. Students were requested to answer 'strongly agree', 'agree', 'undecided', 'disagree' or 'strongly disagree' to each question. A copy of the questionnaire is located in Appendix E.

Table 5-1: Structure of Student Questionnaire

Student Questionnaire		
Question	Purpose	Research Question Element
Part A - Evaluation of Virtual Factory Interface		
1. The INFOstation web pages were uncluttered and clear.	Seeking information on possible modifications to INFOstation's web site and image.	-
2. The number of hyperlinks per page was about right.	Seeking information on possible modifications to INFOstation's site navigation.	-
3. The hyperlinks on the web pages were clearly identifiable.	Seeking information on possible modifications to INFOstation's site navigation system.	-
4. Important information on the ErgoEASE project was easy to find.	Seeking information on possible additions to INFOstation's web site.	-
5. Navigating/finding my way around the INFOstation Ltd. site was easy.	Seeking information on possible modifications to INFOstation's web pages and hyperlinks.	-
6. The instructions in the manager's memos were easy to interpret.	Information on possible modifications to INFOstation's instructions and tasks.	-
7. I had, or could obtain, all the resources I needed to complete the project.	Information on possible additions or modifications to INFOstation's web site, company profile and documentation.	-

Question	Purpose	Research Question Element
Part B - Assistance Provided by Intervention		
1. The use of a real industry scenario added interest to the tasks.	To probe for perceived level of interest. Tasks offering interest are perceived as promoting enthusiasm.	Can delivery of complex, non-quantitative topics be modified to improve student enthusiasm?
2. The use of an industry scenario added relevancy to the tasks.	To probe for perceived level of relevancy. Tasks perceived as relevant are seen as promoting engagement.	Can delivery of complex, non-quantitative topics be modified to improve student engagement?
3. I would recommend that the concept of industry-based scenarios be extended to other engineering topics.	To probe for perceived level of enthusiasm of the intervention. A positive recommendation is perceived as confirming engagement and enthusiasm for the intervention.	Can the delivery of complex, non-quantitative topics be modified to improve student engagement and enthusiasm?

5.3.1.2. Pilot Design – Results of Student Questionnaire, Part A

The results of the student survey using Part A of the questionnaire to evaluate the pilot design computer interface are shown in the following table, Table 5-2.

Table 5-2: Student Questionnaire, Part A

Question (n=51)	Strongly Agree No. (%)	Agree No. (%)	Undecided No. (%)	Disagree No. (%)	Strongly Disagree No. (%)
1. The INFOstation web pages were uncluttered and clear.	7 (13.7)	38 (74.5)	5 (9.8)	1 (2)	0 (0)
2. The number of hyperlinks per page was about right.	4 (7.8)	35 (60.8)	7 (23.5)	4 (7.8)	0 (0)
3. The hyperlinks on the web pages are clearly identifiable.	5 (9.8)	29 (56.9)	11 (21.6)	6 (11.8)	0 (0)
4. Important information on the ErgoEASE project was easy to find.	2 (3.9)	29 (56.9)	15 (27.5)	6 (11.8)	0 (0)
5. Navigating/finding my way around the INFOStation site was easy.	13 (25.5)	28 (54.9)	8 (15.7)	2 (3.9)	0 (0)
6. The instructions in the manager's memo were easy to interpret.	6 (11.8)	29 (56.9)	11 (21.6)	4 (7.8)	1 (2)
7. I had, or could obtain, all the resources I needed to complete the project.	5 (9.8)	27 (52.9)	7 (23.5)	3 (5.8)	4 (7.8)

Merging the positive responses ('Strongly Agree' and 'Agree') and the negative responses ('Disagree' and 'Strongly Disagree') the following table is obtained.

Table 5-3: Pilot Design, Questionnaire (Part A) - Merged Responses

Question	Positive Responses (%)	Negative Responses (%)
1	88.2	2
2	68.6	7.8
3	66.7	11.8
4	59.8	11.8
5	80.4	3.9
6	68.7	9.8
7	62.7	13

From an analysis of Table 5-3 above it can be seen that there was generally a high level of satisfaction with the web site. The highest levels of dissatisfaction identify a pattern

which indicates that further effort should be made to improve the clarity of the hyperlinks and the ease with which project information and resources can be found.

The questionnaire response data in Table 5-2 is shown reformatted in the cluster bar chart below, Figure 5-1.

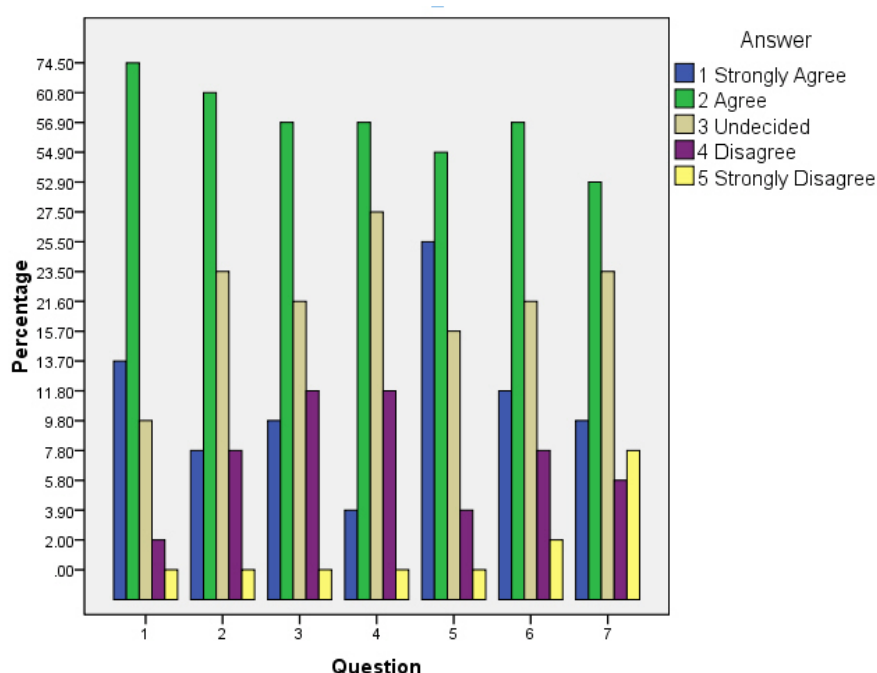


Figure 5-1: Response to Questionnaire, Part A, Pilot Design

5.3.1.3. Pilot Design – Results of Student Questionnaire, Part B

The results of the student survey carried out to evaluate the assistance provided by the pilot design to the reception of the course topics are shown in Table 5-4 following.

Table 5-4: Student Questionnaire, Part B

Question (n=51)	Strongly Agree No. (%)	Agree No. (%)	Undecided No. (%)	Disagree No. (%)	Strongly Disagree No. (%)
The use of a real industry scenario added interest to the project.	10 (19.6)	25 (49)	7 (3.5)	1 (2)	3 (5.8)
The use of an industry scenario added relevancy to the project.	6 (11.7)	28 (54.9)	11 (21.5)	5 (9.8)	1 (2)
I would recommend that the concept of industry based scenarios be extended to other engineering topics.	13.7	64.7	19.6	2	0

Merging the positive responses ('Strongly Agree' and 'Agree') and the negative responses ('Disagree' and 'Strongly Disagree') the following table is obtained.

Table 5-5: Pilot Design, Questionnaire (Part B) - Merged Responses

Question	Positive Responses %	Negative Responses %
1	68.6	7.8
2	66.6	7.8
3	78.4	2

The ratings of Part B of the questionnaire show a high level of positive support for the proposition that the intervention added interest and relevance to the tasks. The highest negative response (11.8) was to the question of the simulated industry placed scenario adding interest to the task. Although 66.6% answered positively to this question the negative response may be due to the fact that this stage of its development the virtual enterprise had only one task of this nature.

The questionnaire response data in Table 5-4 above is shown reformatted in the cluster bar chart below,

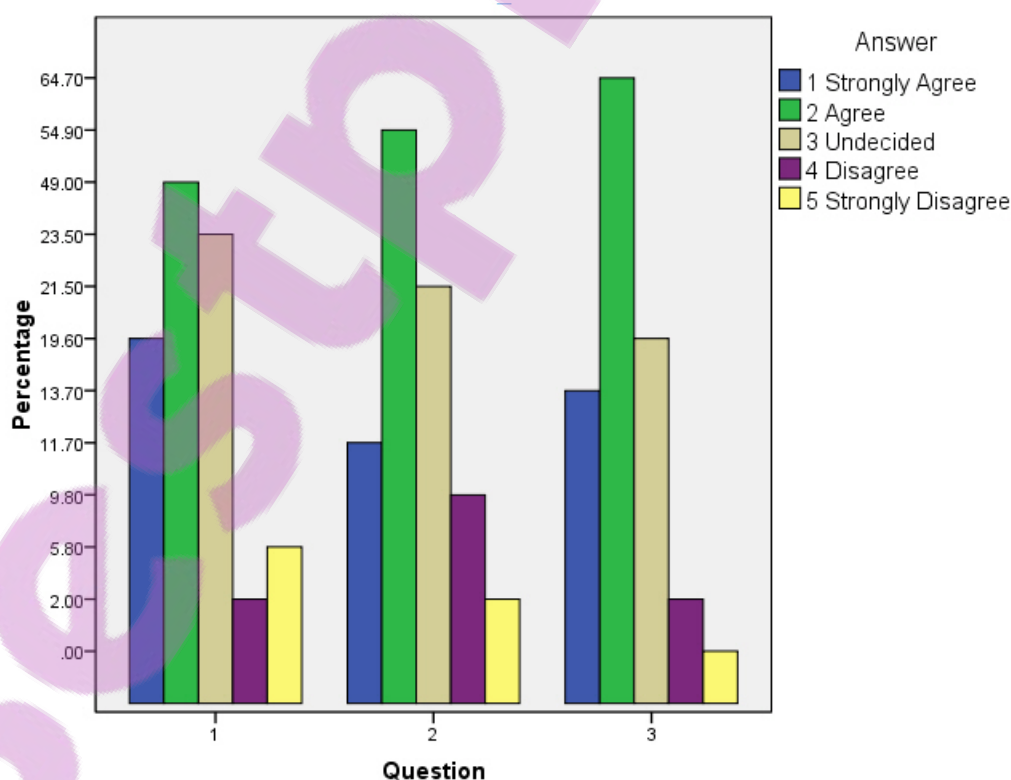


Figure 5-2: Response to Questionnaire, Part B, Pilot Design

5.3.1.4. Researcher Observations

Observations of the students' reaction to the INFOstation web site interface and the virtual environment were made during nine tutorial sessions at which the students accessed the INFOstation web site and navigated through its pages to access information which would enable them to solve a problem in ergonomics. This task, as described in full in Chapter 4, was to investigate an ergonomics issue being experienced by an operator on the INFOstation Limited production line. Students, acting as consulting manufacturing engineers, were to investigate the problem, assess its severity and, if warranted, suggest, design and cost, a possible solution.

On first logging into the INFOstation web site, located on a university network server, the tutorial groups all exhibited a high-level of interest and enthusiasm. This attitude was reflected in comments by students such as:

“Well, this is different.”

“This is good. It is much more interesting than sitting in a lecture.”

“It's like having a new job at a company.”

All students on the manufacturing systems course are computer literate and it was clear that the interest and enthusiasm generated was as a result of being presented with a different learning situation to that of lectures or desk-bound tutorials rather than the use of computer technology per se. Students were curious to explore the extent of the web site and almost all students were observed clicking through the site pages before returning to deal with the ergonomics problem and its accompanying video.

The use of a video clip to present the ergonomics problem instead of a lengthy textual description (which could not have captured all the nuances of the physical operation) proved highly motivating. Students ran the clip a number of times to become familiar with the process cycle before beginning the analysis stage. They were able to slow down and pause the clip when required in order to examine fine detail of the operator's movements. On completion of the analysis stage a number of students made comments to the effect that:

“I spent much more time on this than I would have on a paper problem.”

“Reviewing the video pushed me to do more alternative solutions. On paper I would have done probably only one.”

Discussions with students during the course of the assignment and at its completion were positive. Students felt pleased that they had met the challenge of quickly learning and producing results from a complex software application (ErgoEASE®) in a topic area new to them. Many comments were made about the use of the video clip of a real workplace operation and task and students expressed empathy with, and sympathy for, the hard-working operator in the video clip. Although they had never met her, several students remarked that at the end of the exercise they felt that they knew her well:

“I felt really sorry for her.”

“I thought she was acting to the camera a bit, but I liked the way she smiled.”

“You know, I really wanted to help her out, silly because it’s only an exercise.”

This was a strong indicator that engagement had been achieved with the task scenario and of the immersive nature of the tasks when presented by the multimedia component combination of company memoranda, web-site data, application software and video clips.

Students were prompted to comment on the INFOstation Limited web site and opinion was split approximately fifty-fifty. About half the cohort felt that the web site, particularly the ‘Home Page’ (which consisted mainly of a plan view of the factory) was not the sort of design that a commercial company would adopt for viewing by customers or the public. Other students generally sympathised with this point of view but felt that they could overlook the Home Page because:

“It was good that it was done at all.”

“Yeah, it was OK, it was different and I thought it was interesting.”

“It was a bit more fun than an ordinary tutorial, motivating.”

Student feedback also indicated that there were some pedagogical issues to be addressed within the ergonomics exercise. Some students had difficulty understanding what was required of them. This appeared to be because they were not used to receiving

instructions, or data, in a narrative form. In this case, in the format of a typical company inter-departmental memorandum. Discussions with students indicated that many were somewhat disconcerted when faced with problems presented in any manner other than the typical condensed, non-textualised, text book/examination question format. This unease was, on occasions, expressed with some frustration in comments such as:

“What exactly do you want?”

*“But which answer is the [emphasis] **correct** one?”*

Another issue concerned the ErgoEASE[®] software. Although not particularly difficult to use, the students had little time to become really familiar with it. As a consequence some students attempted to utilise all of the program's analysis modules when only one was required for the purposes of the assignment. This led to some students producing a far wider range of data output as print-outs than were required, or specified, by the memorandum of instructions.

The most frequently voiced criticism of the intervention was the instability of the ErgoEASE[®] software in this exercise. This problem arose because the version of ErgoEASE[®] licensed to the university was designed to be run in stand-alone mode but, for administrative reasons, was being run in a network environment from a network server. This instability meant that occasionally students would complete an analysis in a tutorial session and not be able to reopen their files on a later occasion. This provoked some frustration and annoyance. This issue, however, was used later in a classroom debriefing session to point out that, as practitioners, they would have to deal with similar issues of software and network instability in the workplace and have contingency plans in place to deal with them. Computer crashes are by no means confined to university computer labs. The incidents were also used to demonstrate the relevance of the material, previously covered on the course, on manufacturing data networks and system reliability!

5.3.1.5. Summary

From the observations of students in the computer lab tutorial it was clear that they felt that the INFOstation format made the ergonomics assignment more interesting and more life-like. Discussion with students indicated that they were keen to have other topics delivered in a similar manner. The responses also indicated that further work

should be done to improve students' access to online course material and task information.

The staff involved in the INFOstation project and its application to the teaching of ergonomics issues to engineering students believe that the ergonomics exercise was successful. In delivering the topic in a more immersive fashion students felt that it was more "*realistic*" and more interesting than "*run of the mill*" assignments. The returned assignments were generally of high quality with some students really getting into the spirit of the exercise and formatting their results and commentary in the format, style and language they would be expected to use in a workplace memorandum and formal technical report.

5.3.2. Data – Design Iteration One

As a result of the information gathered from the pilot design application, changes to the design of the intervention were made in preparation for the next iteration of the design, iteration one, and are described in detail in Chapter 4, Section 4.4. In summary, the 'Home Page' was redesigned to have a more 'corporate' look, additional pages were added to show the work of more departments within the virtual enterprise (renamed Team Detectors Limited) and two further tasks were added to the repertoire of the intervention. These were on the topics of facility layout, and production process modelling and simulation. The data collected during the application of iteration one is described below.

5.3.2.1. Student Group Interviews

Following completion of the two new tasks, the factory layout task and the process modelling and simulation task, a sample of 12 students (from a class of 65) were purposively chosen and interviewed to investigate their responses to the intervention and to obtain their opinions about the new Team Detectors Limited virtual enterprise.

The students were randomly selected by inserting the students' names from the class list into an Excel spreadsheet and then allocating a six-figure random number to each name, utilising Excel's built-in random number generator. The random numbers were then sorted into ascending numerical order and the top twelve names on the list were invited to attend an interview. A few invitees were unable or unwilling to attend and they were replaced with the next unused names on the list.

The group interview was used to collect data in this early stage of the intervention's development as the dynamics of the group's interaction with each other was expected to increase spontaneity and freedom of expression of ideas and opinions. It was expected that in discussing the intervention, a topic of interest both to the group and to the researcher, students would be open to share their ideas and opinions and influence each other by responding to the ideas and comments of others in the group. This expectation was validated during the course of the group interview and for many stages of the discussion the researcher was able to 'step aside' and observe the interaction and discussions between members of the group which added further insight into how the intervention might be developed further.

Students were asked to consider, whether or not, they thought the experience had assisted them to appreciate, and be able to deal with, ill-defined and open-ended problems. They were also asked if they felt the virtual enterprise concept was worth continuing with for future courses. The results from the interview were encouraging. Eight of the students felt that the assignment would help them with future 'fuzzy' assignments with incomplete data or and vague directions. The other four students were not sure if the experience would help them or not. The students were unable to say if the experience had prompted them to question the inevitable existence of a 'right' answer to all problems, i.e. to a more relativistic stance. All but two of the students interviewed felt that the virtual factory format should be continued.

At the completion of the semester the students completed a university standard, faculty-wide, feedback form for the course. In this process only three of the students commented specifically on the virtual enterprise tasks. These students commented that the assignment was "*vague*" and, from one student, "*It was confusing. I could only complete it by getting help from my friend.*"

Traditionally, responses such as these would be cause for some concern. However, in the context of this study it was felt that these remarks, and their relatively low number, were interpreted to indicate that the tasks were of about the right level of indeterminacy.

5.3.2.2. Researcher Observations

Informal feedback was obtained from students during computer lab tutorial sessions whilst they were carrying out the new factory layout task. Five students complained that

the documentation for the factory layout task was too vague. A number of students felt that they were being forced, unwillingly, into making difficult decisions which involved choosing the lesser of two evils. Generally however, the feedback indicated that the task was making the students think about what they were doing rather than simply “*plugging numbers into a formula*”. Nevertheless, despite the apparent tendency of the task to encourage a global, or macro, view of the situation within the enterprise, a number of students (approximately 20%) made basic errors such as placing the visitor reception area at the rear of the site and the Despatch Department in the middle of the building with no access to an outside wall or van dock. During the observation period several students pointed out minor inconsistencies in the Team Detectors web site navigation which were corrected immediately. This fault correction action reflects the ‘rapid-prototyping’ aspect of the design-based research methodology not present in controlled experimental methods.

In general, the second new task (process modelling and simulation) was well done and the students observed coped well with learning the basics of Arena®, a professional-level simulation program, with very little tuition time. The main problem faced by the students was in making a decision as to how long to run their simulations in order to get meaningful results from their production line models. Also, what to do to eliminate any queues and bottlenecks in the process uncovered by the simulation. Students became aware of the fact that the better their earlier factory layout solution had been the more efficient their production process would be, and that there were many viable solutions to the task. No-one was going to get the same ‘answer’. Students had deliberately been given little guidance as to what resources of money, staff or equipment could be called upon by Team Detectors Limited to increase the production rate should the simulation show it to be below target. Despite this lack of information most students made an acceptable job of suggesting sensible changes by drawing upon their existing engineering knowledge and general life experience.

5.3.2.3. Summary

The interviews with a sample of students following the implementation of iteration one of the intervention were encouraging. Most students expressing the view that the multimedia concept was involving and assisted them with an appreciation of the ill-defined nature of many issues in manufacturing engineering. The endorsement was not

overwhelming and approximately one-third of the students surveyed were not sure whether they had been helped or not. Opinion on the continuing use of the multimedia based teaching intervention was more consistent with 85% of the students agreeing that the exercise should be continued and developed. Observations of students at work with the intervention clearly showed a higher level of engagement than normally seen when students are working through exercises in textbooks. These observations also laid to rest an earlier concern that the complexity of the software applications which the students were required to use would require too long a learning curve. A very high proportion of students proved to be adept at understanding the concepts behind the software, and put it to practical use, in basic problems, within one or two tutorial sessions.

These results gave encouragement to further developing the intervention with increased levels of corroborative details and realia. Also, the confidence that a further important software application and an associated task could be incorporated into the course without over-extending the students. This new task would complete the natural manufacturing operations progression desired for the course. That is, to build a model that would simulate the gamut of manufacturing systems operations from factory and machinery layout through to final product scheduling, manufacture and delivery.

5.3.3. Data – Design Iteration Two

As a result of the information and comments collected, as described above, further major changes to the design of the intervention were made in preparation for iteration two and are described in detail in Chapter 4. In summary, the web site coding was re-written to take advantage of cascading styles sheets (CCS) to improve style consistency across the site and to make future modifications easier to implement. The site was also redesigned to have a better corporate feel by being ‘product’ focused rather than the existing site’s emphasis on company departments and functions. Details of two more Team Detector products (inflammable gas detectors and dangerous environment, equipment protection devices) were added to the site.

The academic points value of the Manufacturing Systems course within the undergraduate degree programme was increased in the period between iterations one and two and as a result the amount of contact with students was increased. To take

advantage of this increased flexibility the simulation task was expanded and a further task was added on the topic of finite-resource production planning and scheduling.

5.3.3.1. Student Interviews

The interviews commenced with two general questions designed to get students talking and put them at ease. One question elicited discussion about their experiences on a field trip to local manufacturers which was held during the course. The second question asked students their views on an appropriate assessment regime for the course. It was suspected that students would have strong and varied opinions on these issues and a response would not be difficult to obtain. This suspicion proved to be correct and the questions were effective ice-breakers for the later stages of the interview. Discussion was then steered towards the areas of primary interest, the intervention and the virtual enterprise's web site. Questions were also asked on the topics of teamwork, perceived level of immersion and engagement, and the course tasks. A copy of the questions asked to promote discussion and their research function are shown in Table 5-6.

Table 5-6: Student Interview, General Structure, Iteration 2

Student Interview – General Structure			
Starter Question	Purpose	Research Question Element/s	Authentic Learning Element
The Team Detectors concept attempted to place the course topics into a realistic context. What did you think about the attempt?	Authenticity. To determine how the intervention modelled the ‘real-world’ of manufacturing.	Can delivery of complex, non-quantitative topics be modified to improve student enthusiasm and engagement?	Authentic context and ‘real-world’ relevance.
The Team Detectors concept attempted to make the assignment tasks realistic examples of what an engineer might do in the workplace including a certain level of uncertainty in the information provided. What did you think about these attempts?	To probe if problems presented were authentic, and ill-defined to a suitable level of uncertainty, and offered multiple interpretations and solutions.	Can delivery of complex, non-quantitative topics be modified to improve student capability to perceive them as scientific and coherent bodies of knowledge?	Provide authentic activities of an ill-defined nature.
In some of the tasks you worked in small teams. How did you feel about working in teams?	To determine the utilisation of, and enthusiasm for, the opportunities to collaborate and reflect.	Can delivery of complex, non-quantitative topics be modified to improve student enthusiasm and engagement?	Support collegial collaboration in the construction of knowledge. Promote reflection.
What did you feel about the level of assistance provided by the company’s representatives, and the lecturer?	Were opportunities to seek advice from ‘experts’ useful.	Can computer technology help in the delivery of complex, non-quantitative topics?	Provide access to expert examples of performance. Provide coaching.
Do you have any other comments about the virtual enterprise?	To gather other relevant opinions/items not expressed in previous responses.	-	-

5.3.3.2. Student Interviews

Student responses in the interview sessions to the questions in Table 5-6 are reviewed below.

5.3.3.2.1. *The Team Detectors Concept and Authenticity*

The response to the question about the authenticity of the virtual environment intervention, in the form of the Team Detectors Limited virtual enterprise, was overwhelmingly positive. Typical general, initial, student responses were:

“Yes, Team Detectors was good.”

“I liked Team Detectors very much, a good idea.”

Further discussion on authenticity, and questions about whether, or not, the students felt some level of immersion in the intervention, revealed a general consensus that the company seemed a realistic construct. Two students felt that they had been getting too involved and spent more time on the tasks than they would have had the tasks been presented “ordinarily”. Among the comments received were the following:

“I thought the little details helped to make it realistic, like the emails and letters from Chris Waller –is he real?”

“Good idea, the Team Detectors. I did not pick up on it not being a real company until late on in the course.”

“Did not appreciate Team Detectors was a not real company. Thought it must be a real company or they would not have gone to the trouble of getting up a web site if it wasn’t.”

Three students agreed that:

“Team Detectors was good but would have been good to have more to do with the web site.”

Three students also felt that they were disappointed that the virtual company was not a real one and that:

“The Team Detectors scenario should be revealed at the beginning of the course.”

“I thought the concept was good, quite enthusiastic. It would be better if we were introduced to the whole concept, or is it product, at the beginning instead of having bits and pieces revealed as we went through the course, then we deal with individual parts.”

5.3.3.2.2. The Provision of Authentic and Ill- Defined Activities

Opinions were varied, vague, and sometimes non-committal, on the issue of tasks dealing with ill-formed problems with some vagueness in the task specification.

However, a number of thoughtful contributions were made including:

“We both think, yeah, the vagueness was about right” (2 students).

“The assignments I thought backed up the lectures well. But also they weren’t your usual questions.”

“The number of assignments is OK if [they are] not too hard and the information [to get].”

A number of students (6) made the point that they felt that students in general were too spoon-fed with material, making remarks such as:

“I guess you have to get used to not being spoon-fed with the info for the problem.”

“We have stuff coming from all ways. [It’s] good to dig it out [information] for yourself.”

Some criticisms of the tasks in the intervention were made. Generally these concerned the level of difficulty of the tasks or the marks allocated. An attempt was made to determine if these opinions were spread evenly across the student sample being interviewed or were more prevalent amongst students who had produced just one possible solution to a task. It was not possible however to determine this with any clarity. The criticisms included:

“The assignments did not require much depth of thought, not much of a challenge, although there was some thought in the layout and the simulation task.”

“...was not clear about MRP II, need more real life examples. I did MRP II in Commerce, did not get it then either.”

5.3.3.2.3. Teamwork, Collaboration and Reflection

The issue of working in teams elicited an unexpected level of enthusiasm for the activity and the following remarks were typical:

“I liked the team part of projects, like the layout one.”

“The team component of the tasks, like the Layout, was good.”

5.3.3.2.4. Access to Expert Models and Coaching

Observations on the level of support for students and the presentation of the ways in which experienced practitioners go about managing a manufacturing system included:

“It was good, the e-mail. Was that you, for all of them?”

“I reckon I got all the info I needed.”

“The video clips of companies operating were good, not too long. More than about five minutes is, ugh, too long.”

“Those guys at the lean place [Gentrac] were really enthusiastic, I liked them, I don’t think it was for the cameras.”

5.3.3.2.5. General comments

Asked to comment on improvements for further iterations the following responses were made:

“I would like to be able to have our own ‘baby’. Like a set of performance figures of dollars or production output all through the course.”

“...it would be good to have physical examples of the company’s parts.”

“I would like it to be like a management game with teams.”

“A game sort of structure would be good, like a business game and competitive.”

One student made the point that:

“ ...and going to the Team web site costs us money.”

The comments made during the interviews appear to validate the results of the student questionnaire. They confirmed that the teaching intervention was proving useful in improving the delivery of the manufacturing systems course. They indicated also that further modifications could be made to the design of the intervention to improve student satisfaction and level of immersion in later iterations.

5.3.3.3. Researcher Observations

As with the previous applications, observations were made of student activity, chat, more formal discussions and responses to the intervention during class tutorial sessions. These sessions were run in the Faculty of Engineering computer laboratories where students could access the Team Detectors Limited web site and work on the current task. From these labs they could, if required, also upload and run the relevant industrial computer application on their workstation. It was clear, as was to be expected, that the students had a high level of computer skills and were used to the university network environment. No problems were therefore observed in students logging on to the

network and running the correct applications. During the first sessions students expressed interest in, and some admiration of, the Team Detectors Limited web site and it generated much discussion. Most students spent some time exploring the site although most seemed to scan the text material on pages quickly. This is to be expected as it is the dominant way in which site visitors peruse web pages. Towards the end of the session approximately 75% of the students ceased work on the assignment and returned to the web site to examine in more detail the information concerning the company's products. Discussion with several of the students indicated that they felt that they needed to "*get a handle*" on the products to more easily deal with the demands on the assignment.

There were no observations of students appearing to be reluctant to engage with the intervention as a result of feeling self-conscious or of fearing to make mistakes although this is a phenomenon often noted by the researcher in other contexts. One reason for this absence of hesitation and inhibition may be that the 'Manufacturing Systems' course cohort know each other well having worked together on the degree course for the previous two and a half years.

5.3.3.4. Summary

Analysis of the information collected above generally signalled that the basic structure of the virtual environment of the intervention was sound and that further major changes to the virtual organisation were not required. However, what appeared to be necessary was some refinement to the documentation and the details of some of the tasks set to students. The target for iteration number three was to carry out these modifications and to increase the level of immersion and realia associated with the intervention. This would involve the design of an asset register of the company's capital assets with costings, machine hours rates and suitable illustrations and machine dimensions to assist students in the plant layout modelling and simulation tasks. The delivery of iteration number three would also include a pilot survey of student learning styles and level of intellectual development utilising Kolb's 'Learning Styles Index' and Moore's 'Learning Environment Preferences' instruments.

5.3.4. Data - Design Iteration Three

5.3.4.1. Researcher Observations

Observations of the student interaction with the intervention in a tutorial session with twenty students revealed some general consensus on several issues. Several students thought that the virtual enterprise was in fact a real company and expressed disappointment (“*let down*”) when they realised that it was not. Clearly, on balance, students should be put into the picture at the start of the course. One theme that was evident was the students’ general acceptance that team-based assignments, whilst they could cause unwanted aggravation, were worthwhile for the skills they helped to develop. Most students (14) would like to see more team-based work in the course with the proviso that firm steps were taken to deal with ‘freeloaders’. Seven students would welcome the opportunity to change teams from one team-based assignment to the next whilst ten would prefer not to change, three students would be happy with either arrangement.

5.3.4.1.1. Kolb’s Learning Styles Index

Permission was obtained from the licensees, Hay Group Limited, to use the Kolb ‘Learning Style Inventory’ (LSI), Version 3.1, in order to investigate students’ preferred learning styles. The LSI is a self administered instrument containing twelve randomised statements and can be self-scored. Version 3.1 of the LSI has improved psychometric properties and improved internal and test re-test reliability compared to earlier versions. The instrument requires respondents to make a forced choice in ranking available statement endings each of which matches one of the four Kolb learning styles: Concrete Experience (CE); Reflective Observation (RO); Active Experimentation (AE) and Abstract Conceptualisation (AC). Further details of the instrument are contained in Chapter 3, Section 3.4.4.4.

Prior to the survey a memorandum was sent to students explaining the purposes of the LSI and requesting their participation (a copy of the memorandum is located in Appendix D). After recording the results of the survey the completed survey forms were returned to students with their assessed learning style preference. A class discussion was initiated in one lecture period to discuss what the results meant and to suggest how

students might use the information to assist their studies. A total of 74 students completed the LSI. There were no invalid responses.

Figure 5-3 and Table 5-7 below show the results of the survey.

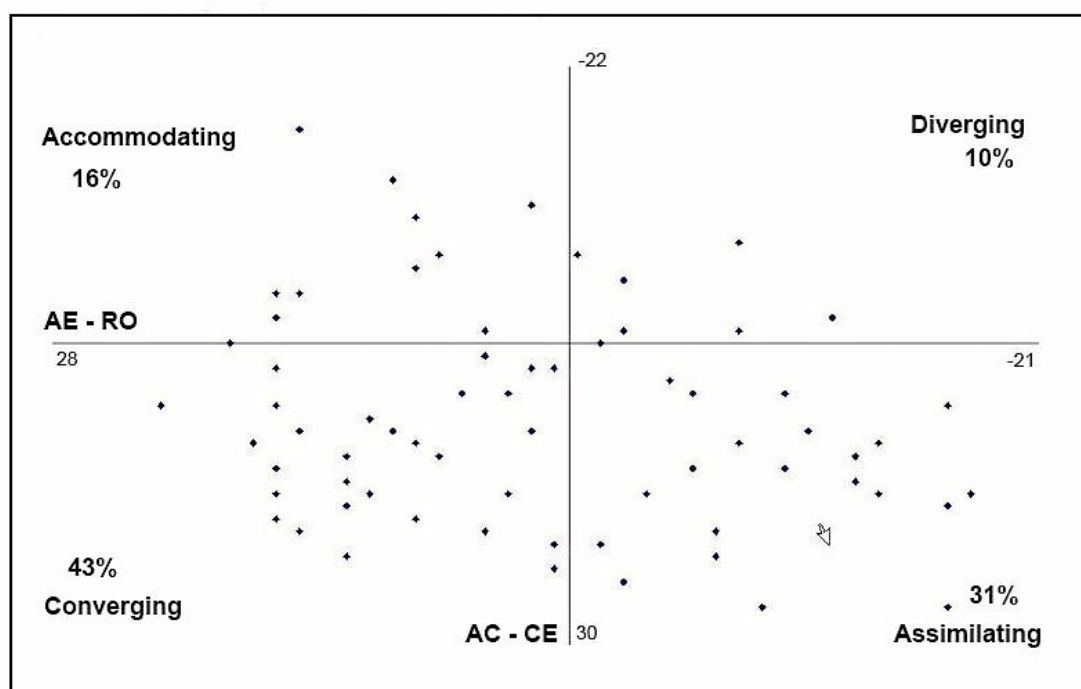


Figure 5-3: Scatter Diagram of Kolb LSI Scores, Iteration 3

Table 5-7: Numbers and Percentages of Kolb Learning Styles

LSI Style (N = 74)	Intervention 3	
	Number	Percent
Assimilator	24	32
Converger	35	47
Accommodator	8	11
Diverger	7	9

Students reporting a converger learning style were 47% of the sample whilst a further 32% were identified as assimilators. A small proportion of the sample were accommodators (11%) whilst divergers made up 9% of the class. These figures are consistent with those reported for civil engineers by Bernold (2000: 191-199), accessed 12/11/2008, at North Carolina State University of 54% Convergers, 33% assimilators,

accommodators 13% and 10% divergers. Sharp (2001), accessed 21/5/2005, in a study of engineering students at Vanderbilt University found that engineering students fell into all of the Kolb learning style categories. The largest number, from a total sample of 1013, were converger (40%) and assimilators (39%) although, throughout her ten-year study, the majority group has switched from convergers to assimilators and back to convergers. Accommodators (13%) have consistently been in third place and divergers (8%) last.

5.3.4.2. Moore's Learning Environment Preference Instrument

The 'Learning Environment Preference' (LEP) instrument developed by Moore is based upon Perry's scheme of intellectual development. The LEP survey covers five domains concerning epistemology and learning: view of knowledge and learning, the role of the instructor, the role of the student and peers, classroom activities and activities, the role of evaluation and grading (Moore, 2000). Each domain contains 13 listed statements and respondents are asked to rate each one on a four-point Likert scale, from 'not at all significant' to 'very significant', and then rank the top three items overall. More details of the instrument are given in Chapter 3, Section 3.4.5.1.

Prior to the survey a memorandum was sent to students explaining the purposes of the LEP and requesting their participation (a copy of the memorandum is located in Appendix D). A total of 35 students completed the LEP. There were 2 invalid responses.

Scoring of the instrument was carried out by the Center for the Study of Intellectual Development who returned an LEP report containing the cognitive complexity index (CCI) for each respondent. The CCI is the most significant of the measures obtained from the instrument and is a continuous scale, numerical index from 200 (approximate Perry position 2) to 500 (approximate Perry position 5). A table showing the correspondence between CCI values and Perry positions is contained in Appendix E.

The results of the application of Moore's Learning Environment Preference instrument are shown below in Table 5-8.

Table 5-8: Perry Positions

Perry Position (N = 33)	Intervention 3	
Position 2	Number	1
	Percent	3
Position 2/3	Number	7
	Percent	21
Position 3	Number	6
	Percent	18
Position 3/4	Number	16
	Percent	48
Position 4	Number	3
	Percent	9
Position 4/5	Number	0
	Percent	0
Position 5	Number	0
	Percent	0

Almost 50% of the students surveyed appeared to be in transition from Perry position three to position four. In this transition stage most knowledge is still viewed from a dualist perspective, i.e. students are beginning to acknowledge that knowledge does have its grey areas, and lecturers may not be infallible. Students may ‘play the game’ and present differing ‘opinions’ about a solution on paper in order to satisfy the lecturer and get a good mark. However this act of discovering and ‘doing what the lecturer wants’, ironically enough (as Perry notes, (1970)) leads to more relativistic thinking and a movement to position four.

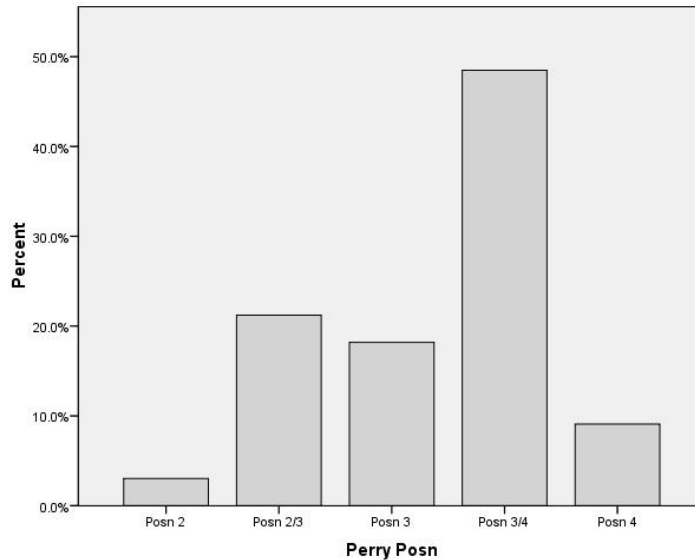


Figure 5-4: Distribution of Perry Positions

5.3.4.3. Summary

From discussions with students it seemed that the original design policy, of letting the students discover for themselves that the teaching intervention was based on a virtual enterprise rather than a real one, was not satisfactory for many students. The decision was made to make it clear to the students, in later iterations, the status of Team Detectors Limited as a virtual organisation.

Observations of the students interacting with the intervention during their work on the tasks, combined with opinions expressed during discussion, made it clear that their shared involvement with the company and its work promoted the use of teams and this element of the course could be expanded with advantage. The results for the pilot LSI and LEP surveys were similar to those obtained in other studies and matched the design of the intervention. The issues of LSI and LEP results are discussed in more detail in Section 5.3.5.5 and Section 5.3.5.6.

5.3.5. Design Iteration Four

5.3.5.1. Student Questionnaire, Part A

The results of the student survey carried out to evaluate the computer interface of iteration number four (the Team Detectors Limited web site) are shown in the following table, Table 5-9.

Table 5-9: Student Questionnaire, Part A

Question	Strongly Agree (No.) (%)	Agree (No) (%)	Undecided (No) (%)	Disagree (No.) (%)	Strongly Disagree (No.) (%)
The Team Detectors Ltd. web pages were uncluttered and clear.	7 (16)	26 (60)	6 (14)	2 (5)	2 (5)
The hyperlinks on the web pages are clearly identifiable.	6 (14)	22 (51)	9 (21)	4 (9)	2 (5)
Important information on the assignments was easy to find.	8 (19)	18 (42)	14 (33)	3 (7)	0 (0)
Navigating and finding my way around the Team Detectors site was easy.	11 (26)	22 (51)	8 (19)	1 (2)	1 (2)
The instructions in the Manager's memo were easy to interpret.	6 (14)	28 (65)	5 (12)	4 (9)	0 (0)
I had, or could obtain, all the resources I needed to complete the task.	12 (28)	23 (53)	5 (12)	3 (7)	0 (0)

Merging the positive responses ('Strongly Agree' and 'Agree') and the negative responses ('Disagree' and 'Strongly Disagree') the following table is obtained.

Table 5-10: Iteration 4, Questionnaire (Part A)-Merged Response

Question	Positive Response %	Negative Response %
1	76	10
2	65	14
3	61	7
4	77	4
5	79	9
6	81	7

An analysis of Table 5-10 shows that there was generally a high level of satisfaction with the web site with no substantial outstanding design issues. The largest negative response was to Question 2 which referred to the page's hyperlinks. Discussions with students indicated that for a few students the link on the Home Page to the University of Auckland secure pages was not very evident. The design was altered to make the link more prominent.

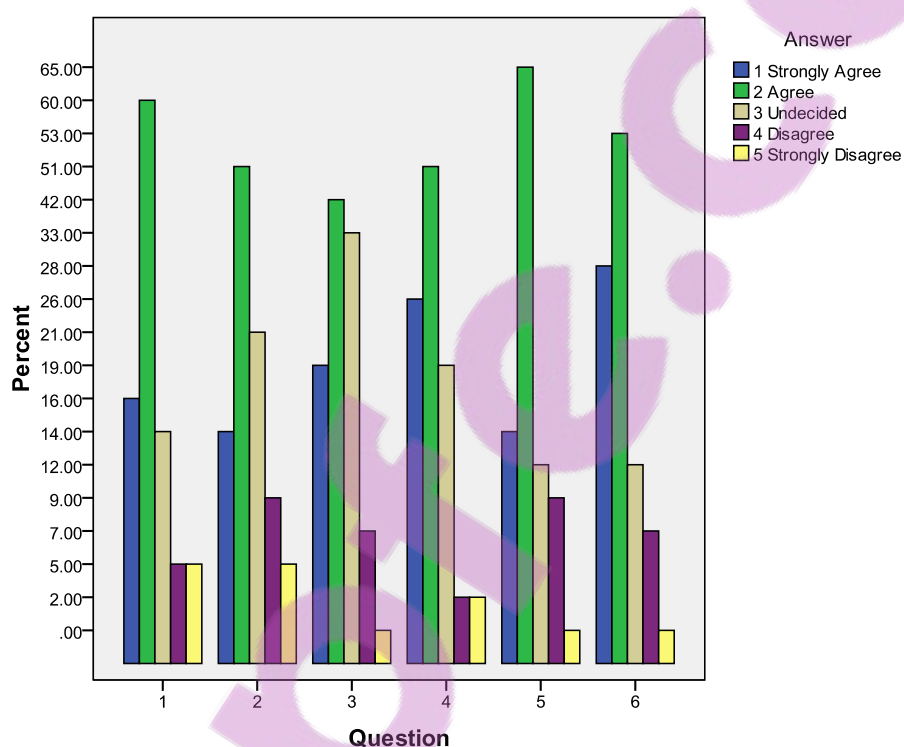


Figure 5-5: Student Responses to Questionnaire, Part A

It is clear from the low percentages of students expressing dissatisfaction with the Team Detector's web site that further major work on its development would be unwarranted and encounter the law of diminishing returns. The average total percentage expressing dissatisfaction ('Disagree' or 'Strongly Disagree') was just 3.5%.

5.3.5.2. Student Questionnaire, Part B

The results of the student survey carried out to evaluate the assistance provided by iteration number four of the intervention are shown in the following table, Table 5-11

Table 5-11: Student Questionnaire, part B

Question (N = 43)	Strongly Agree (No.) (%)	Agree (No.) (%)	Undecided (No.) (%)	Disagree (No.) (%)	Strongly Disagree (No.) (%)
The use of a real industry scenario added interest to the tasks.	13 (30)	18 (42)	6 (14)	4 (10)	2 (5)
The use of a real industry scenario added relevancy to the tasks.	14 (33)	19 (44)	6 (14)	2 (5)	2 (5)
I became more interested in the course material because of the company scenario.	10 (23)	17 (40)	9 (21)	5 (12)	2 (5)
The Team detectors concept helped in understanding how the physical components of a manufacturing plant and the types of organisational; systems used in it work together, e.g. machine tools and scheduling.	9 (21)	24 (56)	5 (12)	5 (12)	0 (0)
The Team Detectors concept enhanced my understanding of the lecture material.	7 (16)	19 (44)	9 (21)	4 (9)	4 (9)
I would recommend that the concept of industry based scenarios be extended to other engineering topics.	16 (37)	15 (35)	7 (14)	1 (2)	3 (7)

Merging the positive responses ('Strongly Agree' and 'Agree') and the negative responses ('Disagree' and 'Strongly Disagree') the following table is obtained.

Table 5-12: Iteration 4, Questionnaire (Part B)-Merged Responses

Question	Positive Responses %	Negative Responses %
1	72	15
2	77	10
3	63	17
4	77	12
5	60	18
6	72	9

The analysis of Table 5-12 shows that, compared to the pilot course, there was a slight increase in the percentage of students who thought the industry scenario added interest

to the tasks (68.6 to 72) and relevancy to the tasks (66.6 to 77). However there was a slight decrease in the percentage of students who thought the scenario should be extended to other engineering topics, from 78.4 to 72. There was also a decrease in the number of 'Undecided' responses to the three questions common to both the pilot design and iteration 4 questionnaires. The average 'Undecided' percentage falling from 16 to 6.5 and this seems to have raised the percentages of negative results for the questions.

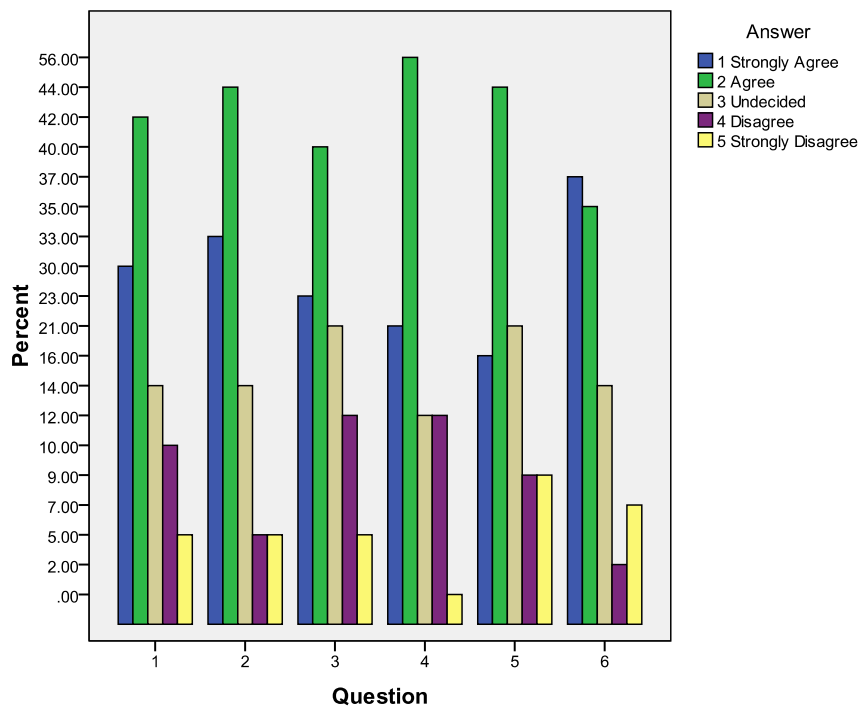


Figure 5-6: Student Responses to Questionnaire, Part B

5.3.5.3. Student Semi-Structured Interviews

Twenty students took part in the interview exercise (25.5% of the cohort). The random sample was chosen using the technique described earlier in Section 5.3.2.1.

As in previous iterations the interviews commenced with two general-purpose questions designed to get students talking and put them at ease as with the interviews for iteration number two. The questions concerned a field trip to local manufacturers held during the course and the issue of appropriate assessment methods.

The discussion was then steered towards the areas of primary interest, the intervention and the virtual company's web site and how they students perceived it. Questions were also asked on the topics of teamwork, immersion and tasks. A copy of the questions asked to promote discussion, their purpose, and relevance to authentic learning pedagogy, are shown in Table 5-13.

Table 5-13: Student Interviews, General Structure

Student Interviews – General Structure 2			
Starter Question	Purpose	Research Question Element/s	Authentic Learning Element
The Team Detectors concept attempted to place the course topics into a realistic context. What did you think about the attempt?	To determine how the intervention modelled the 'real-world' of manufacturing. Authenticity.	Can delivery of complex non-quantitative topics be modified to improve student enthusiasm and engagement?	Authentic Context and 'real-world' relevance.
The Team Detectors concept attempted to make the assignment tasks realistic examples of what an engineer might do in the workplace including a certain level of uncertainty in the information provided. What did you think about these attempts?	To probe if problems presented were authentic, and ill-defined to a suitable level of uncertainty, and offered multiple interpretations and solutions.	Can delivery of complex non-quantitative topics be modified to improve student capability to perceive theme as scientific and coherent bodies of knowledge?	Provide authentic activities of an ill-defined nature.
In tasks such as the layout, ergonomics and simulation tasks you were able to view the problems from the point of view of different members of the company. Did these different views help in your understanding of the topics and the solutions' complexities?	To determine what points of view students adopted and if these students found the intervention helpful in understanding the topics.		Provide multiple roles and perspectives.
In some of the tasks you worked in small teams. How did you feel about working in teams? Was there an exchange or change of views in discussion?	Utilisation of, and enthusiasm for, the opportunities to collaborate and reflect.	Can delivery of complex non-quantitative topics be modified to improve student enthusiasm and engagement?	Support collegial collaboration in the construction of knowledge. Promote reflection.
What did you feel about the level of assistance provided by the company's representative, the lecturer?	Were opportunities to seek advice from 'experts' useful.	Can computer technology help in the delivery of complex non-quantitative topics?	Provide access to expert examples of performance. Provide coaching.

What did you think about the assessment being tied to each task and solution and the assessment formats.	To examine opinions about the integration of assessment into tasks, relationships between tasks.	Can delivery of complex non-quantitative topics be modified to improve student capability to perceive theme as scientific and coherent bodies of knowledge?	Provide for integrated assessment.
Did you find that the relationships between the topics in, and between, the course(s), were made evident?	To ascertain level of appreciation of 'integration'.		Use of tacit knowledge, articulation with other courses.
Do you have any other comments about the virtual factory?	To gather other relevant opinions/items not expressed in previous responses.	-	-

5.3.5.3.1. *The Team Detectors Concept and Authenticity*

Students were generally enthusiastic about the Team Detectors virtual enterprise intervention and the aim of placing the course topics into an authentic context. Eighteen respondents commenting favourably, whilst two were unimpressed. Comments from students included the following:

“Team Detectors was a good supplement and the web site was good.”

“Team Detectors was good, there should be more relevant stuff like this.”

“I thought the idea was well presented. I was impressed with the trouble that was gone to.”

“In my opinion what you call the virtual factory was quite refreshing.”

“Yeah, with Team Detectors I liked what you did, appreciate what you were trying to do.”

“The Team Detectors made me pretty interested in most of the stuff we did except the CNC.”

“Nah, I don’t like computers too much. I prefer just the basic information really.”

“If you don’t mind me saying so. I didn’t pay that much attention to it to be honest.”

The intervention appeared to promote enthusiasm and engagement amongst students with nine students commenting favourably with remarks similar to this student's:

"Definitely made the course more interesting."

On the issue of the level of immersion students had this to say:

"Well, really, I thought it was a real company. Wow, it was very realistic."

"I though the Detectors company was a real company for a long time."

"I liked the Team Detectors concept, could it be made even more immersive" (four other students made similar comments).

"I knew at the beginning that Team Detectors was not a real company but that was only because I Googled it and saw your published papers about it. If I hadn't done that I'd say it was definitely believable."

As a result of feedback from iteration three the students were told of the virtual factory concept in the first lecture of the course and its purpose explained. Nevertheless the following comment from one student was repeated in a similar vein by three others:

The lecturers should tell us the full story at the start, that would be better.

5.3.5.3.2. The Provision of Authentic and Ill-Defined Activities

"The Team Detectors concept was good and the exercises were interesting. It's a bit like having a job."

"The ergonomics was good, and useful."

"With ergonomics a big chunk was common sense. Probably too much of it – you can pick up a lot of it in your vacation jobs."

"I liked the simulations, it was hands on. It added a lot of interest to me."

"I like these problems. There a bit more like real ones. In other classes you're just putting numbers into formulas".

"I felt I was acting like a pro".

“Digging the thing that was actually wanted out of the memos was hard. I was annoyed at first but that’s what happens at work I suppose. So I suppose it’s real”.

“It’s weird. At home I kept thinking that if I have one more go at Arena I might get a better result, flow. It’s a bit addictive”.

“The learning by the tasks makes things hit you better. You see the things in action.”

“The marks for Task 2 [‘Push’ Simulation] and Task 4 [‘Pull’ simulation] didn’t seem to agree enough with the extra work needed for Task 2.”

Another student commented:

“I thought that the Preactor [task] was a bit rushed.”

One student responded that he:

“...liked the way the Team Process Chart was linked to the Preactor scheduling.”

And added, but:

“You should add costings to the assignment to add challenge.”

Two students interestingly used the word ‘job’ rather than ‘question’ or ‘problem’ when commenting on the ergonomics task suggesting a certain amount of immersion in their role as consultant to Team Detectors Limited:

“I liked doing the, sort of, jobs for Team Detectors.”

“There should be a better tie up between the ergonomics job and Team Detectors’ other jobs.”

“The layout task really could he help me to see stuff”.

The tasks contributed to thinking about the relevance of data supplied:

“The task of the facility layout was good as it was hard to know if you should treat it as a typical university project or think outside the box and have a risk of not doing what was wanted.”

“I thought that the assignment data was not too wordy. We had to think about what was relevant, like in a real job.”

“In the Arena simulations you could see the [factory] work all piling up.”

Not all students became involved:

“Involved? Not really. It might just be my approach I just look at the assignment and do what is wanted.”

“I only gave a quick look at the extra [corroborative] material.”

“Did not refer to the financial stuff but the list of machines [Capital Equipment Register] was good and the product description was very interesting.”

“For the assessments I did not really need all the background in the assignment page sheet.”

For some students the second simulation task was not satisfactory:

“The assignments were okay but the second Arena task [‘pull’] was pretty easy.”

“The ‘pull’ task was a bit easy.”

“The PUSH and PULL tasks, the Arena thing. They could be integrated better.”

A common complaint from students concerned the simulation program, Arena®. The version of the program available to students had a limit of 150 entities (production parts) allowed to be present in the model at any one time. In earlier versions of the intervention this restriction had not generally been an issue since the models, and the simulations run on them, had been less complex. With greater confidence in the ability of students to cope with more difficult tasks the models and simulations expected from them had grown in size sufficiently for the 150 entity limit to become a nuisance.

5.3.5.3.3. Topic understanding and multiple viewpoints

Students also often emphasised the assistance provided by the intervention in understanding the course material:

“It was realistic, made the projects more realistic. Could you base it on Fisher and Paykel or Criterion?” (local manufacturing companies).

“Yes, I thought Team Detectors was good it made a whole bunch of theories more interesting. It put an image in my head and helped me remember.”

“The Team Detectors thing helps to understand the course. It was especially good for the first part, the [factory] layout goals that we had to consider.”

“Team Detectors was good. Listening to somebody just talk about topics it is one thing but seeing it in use like at a real company or a virtual one like Team Detectors is much better.”

“Did Team Detectors make the material more clear? Yes absolutely.”

“I really enjoyed the projects especially the layout and the first Arena one.”

“With Team Detectors in the background it made the assignments seem more clear to do and made them easier.”

“Learning with Team Detectors and the simulations made the subjects hit home a lot more.”

“It, [the simulation] helped to understand, when you see the machines working and the parts moving along, in action, which you can't see when you're listening to a lecture.”

“Doing it with a computer made the notes much easier. Like for Pull Systems and Kanbans. They were a bit foggy but doing it made it all make sense.”

One student found that relatively common teaching aids took on a greater significance when used in the context of the virtual enterprise:

“The videos and film gave a personal touch to the course that I haven't met before.”

5.3.5.3.4. Teamwork, Collaboration and Reflection

As with previous interview exercises there was overwhelming support for working in small teams.

"I would like more teamwork."

"I like team assignments there should be some more."

"Yes, I like to do assignments in a team as long as it is a good team."

"I like teamwork, especially if you're with the right team, it makes you more productive and you all come up with way more ideas. By year three second semester you know pretty much everyone in the class but you don't know them. in a team it gets quite nice to meet with the others."

"Working in the teams helped us to learn more about the topic."

"Talking about the software and the output in the team helped a lot. We had a good group, very together."

"Yes, the teams helped we discussed he topics and knew more."

"We had some issues and disagreements with versions of the layout. But we worked it out with discussions."

"I can see that being able to work in a team would be good for the future".

"It made you think. You felt like you were taking some personal responsibility for the thing being right."

Two students made valid points about the practicalities of student collaboration:

"Sometimes, though not often, some people stop contributing if they think you have got more marks than them."

"I'm pretty easy about teamwork. I can take it or leave it. We all end up collaborating anyway."

5.3.5.3.5. Access to Expert Models and Coaching

Students were exposed to many multimedia examples of expert performance during the course. Some was textual, some verbal from the course presenter but primarily it was via video clips. The video examples were of professional manufacturing engineers dealing with day-to-day problems in industries as diverse as Disney World, Hershey Chocolate, British Aerospace, Boeing Aircraft and a government social services system. Most problems appeared to be solved in team discussions but some students made use

of the facility to email one of a number of specialists at Team Detectors Limited for advice and information.:

“It is good what you are trying to do with Team Detectors. The idea about the main [senior] staff and emailing them was good and the products too.”

“It was cool, mailing the Factory Manager and getting a reply.”

“I emailed Chris Waller about the scheduling task, that helped –was that you, was it?”

I really liked the e-mail to the Team Detectors guys. It was like they really wanted to help get the job done.”

“The guy with the glasses was good for lean [Factory Manager at Gentrac Ltd.], and the little lady [operator] explained it good.”

5.3.5.3.6. Integrated Assessment

Students were asked about their opinions on the assessment regime applied to the course:

“The way the jobs all interconnected, that was good.”

“I thought the assignments were very good, tops, great.”

“What I liked was the way the tasks joined together. That made them make sense, yes. ...much better than ordinary lecture test questions.”

“The jobs joined together, like a story. Also I liked the often, little assessments.”

“Yeah, the task - assessment, task -assessment thing was good. It helped me, I think, to keep on track.”

“With the high-level of internal assessment it helped to make it interesting. I was more motivated to play with the software we did.”

“Yes it definitely motivated you” (the tasks/assessments).

A few students (5) felt that more work could be done on integrating the tasks into a coherent stream. For example:

“Perhaps they could do a better job of integrating all the other tasks. You should definitely carry on with it.”

“Could there be more connection between the tasks - there was some.”

“The thing about the reports was you were writing it like something would be done about it by the boss, when he got it. Not like usual essay type things.”

As far as the assessment scheme in general was concerned most students took the view that:

“The number of assignments was about right/OK.” (Eight students with similar comments).

Several students however (4) felt that they could be stretched more. For example:

“I thought we could do more coursework. It was not particularly onerous. Myself, I was not particularly pushed.”

“There were the right number of assignments. Maybe we could have a couple of tests too.”

Whilst one student commented:

“The assignments seemed to be more about learning the computer programs than course material.”

5.3.5.3.7. Utilising Tacit Knowledge

“The task notes, they encouraged you to read your course notes even the ones not for the assignment.”

5.3.5.3.8. Other Comments

“Maybe you could explain the Preactor program concepts in more detail.”

“We could have done with some assistance and more information about interpreting the reports from Arena.”

“I really thought that too much help, assistance, was given to some in the Preactor tutorials. They should have worked it out for themselves.”

"I didn't have high expectations when I enrolled for the course. I enjoyed it much more than I thought I would."

5.3.5.4. Researcher Observation

In this series of observations the Observation Chart, described in Chapter 3, Section 3.4.4.3, was used in addition to field notes. The cohort was split into three sessions and the activities of five students were recorded on the chart at each session as described in Chapter 3. A high percentage of the time 45% students were recorded as working on the task with enthusiasm and motivation and immersed in the task (Production Scheduling) and 21% of the time working with a team member.

The full figures were:

- 45% - Immersed in task.
- 21% - Working on task with a team member.
- 16% - Listening to other student talking on task.
- 18% - Uninvolved in task (talking off task/unrelated material on computer screen).
- 5 events - Moves to help other student.
- 6 events - Asks other student for comment.
- 8 events - Asks other student for help.
- 3 events - Makes negative task comment.

Students working on the production scheduling tasks with the software application Preactor® tasks, were observed to work in informal teams (of two generally) to approach the problem and assist each other with applying the software, an example of distributed cognition. There were many solutions to the problem of scheduling a mix of different products and quantities through Team Detector's production process in a fashion that would produce as many on-time deliveries as possible. Selecting the best combination of products, customer orders and production schedules at the same time as ensuring that the parameters in the software database were correct, lead to some very animated students who became extremely involved in the problem and quite concerned if one of their customers appeared likely to receive a late delivery.

Observations were made of the students' interaction with the intervention from the point of view of how immersive they felt the scenario to be. These observations made it clear that, although, the students made remarks such as *"I have to deliver this detector by the due date or I will be in trouble"* which indicated some level of identification with the

company's virtual staff. Nevertheless, they seemed the same time to have one eye on what the lecturer/assignment marker wanted. This stance was demonstrated by questions to the observer such as *"This isn't very clear, what exactly do you want in my answer?"* The researcher in these instances, acting as coach and providing advice, suggested that they should ask themselves, or a colleague, 'what would the company want?' Students were told to consider the virtual company and its requirements as their focus and the company's manufacturing manager to be considered the person to whom they reported the results.

The academic environment appears to mediate against attempts at making the tasks totally immersive, at least for some students. It was clear that whatever was said about playing the role of a consultant to the virtual company the final objective, as far as some students were concerned, was to satisfy the marker and get a good grade. This reaction is understandable since the environment the students have inhabited at university since their commencement of degree studies has been to do what the marker wants and get marked appropriately. As one student remarked, *"that's really the reality"*.

If the classroom will always be the classroom, where learning is done, and the 'real-world' will always be a separate 'real-world', where the professional work, then considerable effort will have to be put into any attempt at immersive and authentic virtual worlds if the separation of learning activity from simulated authentic professional activity is to be broken down.

5.3.5.5. Kolb's Learning Styles Index

Version 3.1 of Kolb's LSI was applied to the cohort of students exposed to iteration four of the intervention. The instrument was administered twice, once at the commencement of the manufacturing systems course and once at its end. The procedure adopted was identical to that described for its application to students exposed to iteration three of the intervention, as described in Section 5.3.4.1.1.

The results of the application of Kolb's Learning Styles Index to iteration number four are shown in Table 5-14.

Table 5-14: Mean and standard deviation scores, Kolb primary variables

Variable		CE	RO	AC	AE	AE-RO	AC-AE
Pre-course (N = 72)	Mean S.D.	22.78 5.08	27.67 6.10	34.57 5.89	34.97 5.88	7.31 10.22	11.79 9.15
Post-course (N = 40)	Mean S.D.	20.95 5.77	26.88 5.01	34.45 6.95	37.70 5.93	10.83 8.66	13.5 10.85

Table 5-15: Numbers and percentages of the four Kolb learning styles

LSI Styles		Intervention 4 (Pre-course, N= 72)	Intervention 4 (Post-course, N=40)
Assimilator	Number Percent	23 31.9	10 25.0
Converger	Number Percent	30 41.6	23 57.5
Accommodator	Number Percent	10 13.8	3 7.5
Diverger	Number Percent	9 12.5	4 10.0

Figure 5-7: Learning styles, Pre and post course, Iteration 4

Examination of the results from the LSI surveys show that about 50% of the cohort are convergers whose preferred learning approaches are Abstract Conceptualisation (AC) and Active Experimentation (AE). Convergers' strengths lie in the practical application of ideas and prefer problems to have a single correct answer. This learning style is characteristic of many engineers.

The next largest group are assimilators (approximately 30%) whose preferred learning approaches are Abstract Conceptualization (AC) and Reflective Observation (RO). These students strengths are inductive reasoning and in forging a variety of observations into an integrated explanation. If the 'facts' of a situation do not match their theories they are likely to prefer the theory over the facts. This learning style is relatively common in engineering and found often in research and development areas.

5.3.5.6. Moore's Learning Environment Preference

The results of the application of Moore's Learning Environment Preference instrument to iteration number four are shown in Table 5-16 and Figure 5-8.

Table 5-16: LEP Results, Iteration 4

Perry Position (N = 44)	Intervention 4	
Position 2	Number	3
	Percent	7
Position 2/3	Number	11
	Percent	25
Position 3	Number	15
	Percent	34
Position 3/4	Number	12
	Percent	27
Position 4	Number	3
	Percent	7
Position 4/5	Number	0
	Percent	0
Position 5	Number	0
	Percent	0

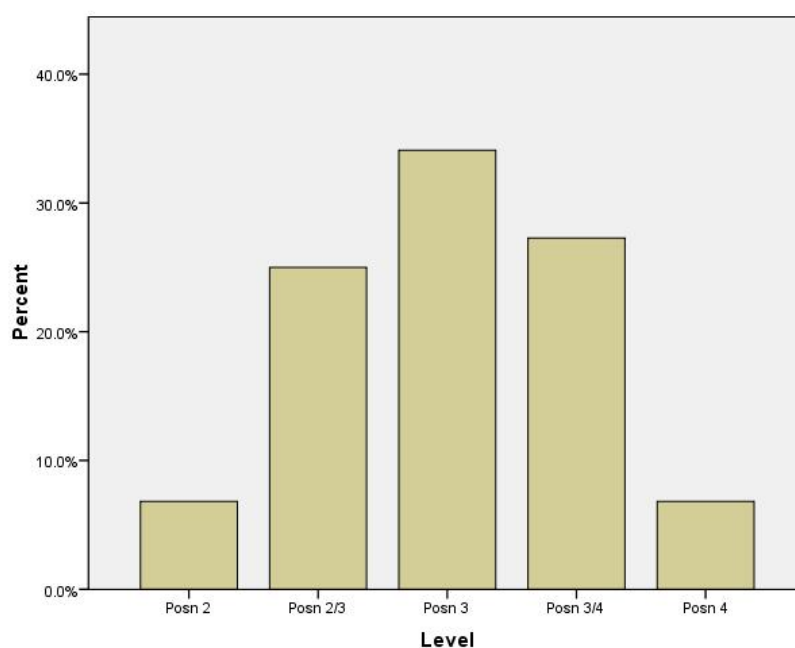


Figure 5-8: Distribution of Perry Positions, Iteration 4

The spread of Perry positions appears to be fairly normally distributed. The mode is position 3 with approximately equal percentages of students in transition from position 2 to 3 and from position 3 to 4. The average is 3.2. These figures are close to those obtained by Palmer et al. (2000) who carried out a longitudinal assessment programme of engineering students. The results for 32 students in year three of their degree showed that the modal position was position 3 and the average 3.38.

For this study the largest group of students (34%) are in the stage of Early Multiplicity where the student realises that it is impossible to continue to ignore the possibility of multiple points of view although he, or she, still believes that there is only one answer. At position 3/4, Early Advanced Multiplicity, students come to believe that accepting uncertainty in solutions is a legitimate stance even though they still fundamentally believe that solutions are either right or wrong and 27% of the students were recorded as being in this category. For the 7% of students in position 2, and to a lesser extent those in transition from position 2 to 3 (25%), their Dualism (some shades of grey may exist but there is only one answer to any problem) will make the completion of the tasks more difficult. These students will require to be encouraged to change either stance by the challenges of the indeterminacy of, and multiple answers available, to the tasks which are presented to them.

6. Discussion, Conclusions & Recommendations

6.1. Introduction

This chapter presents a summary of this research study and describes the important conclusions which were drawn from the results data presented in Chapter 5. It provides some suggestions for action for and improvements to current practice in the delivery of complex, ill-defined courses to engineering students. It also makes some recommendations for further research in this field.

6.2. Summary of the Study

The purpose of this study was to investigate the problems which arise in the delivery, to engineering students, of complex, ill-defined and predominantly non-quantitative domains and to create novel, pedagogically sound, solutions to reduce or eliminate them. This was to be done by investigating how computer-based multimedia technology could best be applied to this category of courses.

6.2.1. Overview of the Problem

The problems referred to above are recorded in the engineering education literature and have been observed by personal experience. They are made manifest in the students by: a lack of motivation or interest in the domain; low levels of engagement with the course; little, or no, awareness of the integrated nature of the topics presented; and a low tolerance for, and acceptance of, the indeterminate nature of many engineering problems. The particular ill-defined domain targeted in the study was that of manufacturing systems, although the problems described occur in teaching other domains with similar ill-defined characteristics, such as engineering management and operations management.

The general lack of motivation displayed by students appears to arise because the concepts within the domain are typically delivered in a traditional, didactic, lecture-based, fashion as a collection of separate topics with the connections between the topics not clearly apparent (Bowden et al., 2006, Goodyear, 2000: 1-18, Jackson and Muckstadt, 1994). Many of the topics in manufacturing systems are concerned with non-quantitative content (inter-personal communications, data collection, human performance and relationships) which is difficult to demonstrate, explore or manipulate in conventional lecture or laboratory sessions. Students find it hard to ‘get a handle on’ these issues and, as a result, do not generate much enthusiasm for, or interest in, the topics. Another factor in the low levels of motivation and engagement reported is the indeterminate nature of many problems and the frequent use of heuristic and non-quantitative methods of problem solution. This leads students to categorise the domain as ‘not scientific’ and ‘not real engineering’. Further, undergraduate students typically have little, or no, practical experience of operating in the manufacturing sector and often have a very vague idea of how their own designs might be manufactured in quantity at a competitive price, or of the typical activities of a manufacturing engineer.

6.2.2. Purpose Statement & Research Questions

The purpose of this study was, firstly, to identify and investigate the factors that bear upon the student attitudes described and the ways in which computer-based multimedia technology could be used to improve the delivery of ill-defined domains. Secondly, to design, build and evaluate a novel and effective computer-based, multimedia, immersive teaching intervention, built upon a valid and appropriate pedagogical framework, to inform and improve courses in complex, ill-defined engineering domains. Specifically, for this research study, the domain of manufacturing systems. Finally, to establish a design methodology for the design and delivery of this category of courses and to validate the intervention and the methodology by its implementation in practice and the analysis of student feedback.

The problem statement, documented in Chapter 1, Section 1.3, concerning the *effective* utilisation of computer technology in teaching and of the application of a suitable pedagogical theory to underpin its use (in particular for engineering domains such as manufacturing systems) led to the following research questions:

1. How can the current delivery of complex, ill-defined and non-quantitative topics such as manufacturing systems be modified to improve student (a) motivation, (b) engagement and (c) capability to perceive them as coherent and scientific bodies of knowledge?
2. What specific educational theories and pedagogical strategies would effectively form the framework for this improvement?

6.2.3. Review of the Methodology

The solution process involved a wide-ranging and thorough literature review examining the factors that might impact on the delivery, and reception by students, of these ill-defined domains.

The review began with an examination of the major philosophical theories and approaches to understanding how learning takes place. This effort was to ensure that the appropriate theories were applied and to clarify the researcher's position on the ontological and epistemological issues to be faced. The most widely accepted theories concerning personal motivation and of student learning approaches to study were researched and noted to assist in finding solutions to the student motivation and engagement issues with which the research study is concerned.

The use of narrative and stories in education was examined with a view to utilising these features to assist in raising levels of engagement and motivation and in structuring the design of the teaching intervention. Then an examination of the pedagogical literature led to the adoption of the theory of situated learning based upon work by Herrington (2006: 3164-3173) and Lave (1991). This research was based on a social-constructivist view of learning and the pedagogical framework of situated learning was deemed suitable for the implementation of the intervention as a result of its constructivist approach and emphasis on the use of authentic content and context.

The literature on the application of computer-based technology to engineering education was extensively researched. A number of examples were examined of the application of multimedia, games and simulations to the teaching of ill-defined and complex domains such as engineering design, engineering management and manufacturing systems. No examples were found in the literature which adopted the solution of a high fidelity,

narrative-led intervention within a compatible pedagogical framework such as situated learning.

Commonly utilised pedagogical taxonomies such as Bloom's taxonomy and Gagne's Conditions of Learning theory were reviewed and noted as aids to ensuring that the topics were covered at the appropriate level and in the appropriate sequence.

The research was carried out utilising a design-based research methodology and four iterations of the teaching intervention. This methodology was selected as being in alignment with the teaching environment within which the study was to be carried out and because it offered a way to seek answers to open-ended questions such as, 'what are the factors that can improve student motivation in multimedia courses?' rather than attempting to compare methods by asking, 'are multi-media methods of presentation better than traditional lectures in motivating students?'

Following the literature review, the solution to the research problems which was adopted was to create and implement a novel teaching intervention which grew into a complex, narrative-led, virtual enterprise - Team Detectors Limited. The virtual company incorporated a wide and complex product range to enable the coverage of a wide variety of manufacturing processes and systems operations. To add corroborative detail the realia surrounding the company included a commercially hosted web site, a full set of company documentation including human resources and capital equipment registers, financial performance records and financial forecasts, full bills-of-materials, together with costings and process times for the product range. Also available was a 3D walk-through model of the plant which included all the major items of manufacturing, storage and materials handling equipment.

Student interaction with the company involved them in planning department and equipment layouts, carrying out ergonomic checks of workstations, production process modelling and simulation, and process planning using finite resource scheduling methods. To assist in these tasks the company made available to students the use of three widely-used industry software packages—Arena® for simulation modelling, ErgoEASE® for ergonomic analysis and Preactor® for finite resource product scheduling. Students were able to contact virtual members of Team Detector's staff for advice and information on the company and its products. The company was designed

and developed over four iterative cycles and informed by feedback from users utilising questionnaires and semi-structured interviews. The data was supplemented with observation, by the lecturer, of the virtual enterprise in use by students.

Appropriate videos were utilised to demonstrate the activities undertaken within manufacturing systems by manufacturing engineers. These depicted engineers, as experts, in a number of industries from entertainment to manufacturing and from consultants working in simulation software development to those working on systems for social services organisations. These videos demonstrated that manufacturing systems principles can be applied in a wide range of industries and that solutions are as often of the result of compromise and negotiation as of quantitative evaluation.

The issue of low levels of motivation and engagement were addressed with the implementation of the virtual enterprise. This provided an authentic context in which the sequence of topics made logical sense, were humanised (with virtual staff) and where tasks were presented with authentic content in a logical order. The issue of indeterminacy and ill-definition were dealt with in the specifications, sometimes vague, of the tasks to be undertaken and for which various solutions, provided they were workable, were acceptable. The believable and highly detailed narrative and comprehensive set of realia, within which the virtual enterprise was set, also assisted in making clearer the tasks undertaken by manufacturing systems engineers and the integrated nature of the topics within the domain. The use of real, industry-standard software, rather than 'home-made' practitioner developed applications, for major systems tasks increased levels of motivation and enthusiasm and the realism of the virtual enterprise. Also assisting was the expert assistance given by the virtual members of the company's staff.

The narrative presented a logical series of tasks and events which assisted students to impose their own cognitive order upon the course material. This provision by the narrative of a coherent structure is a leading factor in achieving an important goal for the research effort. That is, to make the inherent integrated nature of the course topics, and the manufacturing systems domain, more evident to the students and eliminate the notion, which had been evident at the commencement of this research programme, of a course consisting of a disconnected collection of topics.

6.3. Major Findings

Data collected during the research effort indicated that the Team Detectors Limited intervention was successful in meeting the research goals of improving the delivery of a course of a complex non-numerical nature e.g. the University of Auckland course in manufacturing systems for Year Three mechanical engineering students.

The results indicate that this immersive, multimedia based, intervention was successful in increasing level of student interest in the course topics, was successful in raising levels of motivation and enthusiasm and was also successful in conveying to students the integrated nature of manufacturing systems operations. This is despite the wide variety of topics, tools and disciplines which are included under the heading of manufacturing systems. The success of the effort to encourage the suspension of disbelief is shown in the following sample of responses from the semi-structured interviews.

“I thought the Detectors company was a real company for a long time.”

“Good idea, the Team Detectors. I did not pick up on it not being a real company until late on in the course.”

The major findings are described below in relation to the elements under investigation in the research questions.

6.3.4. Research Question 1

The following sections describe the findings in relation to the problems contained in research question 1. Note that this item can be split into two factors — integration and indeterminacy.

How can the current delivery of complex, ill-defined and non-quantitative topics in courses such as manufacturing systems be modified to improve student (a) motivation, (b) engagement and (c) capability to perceive them as coherent and scientific bodies of knowledge?

6.3.4.1. Levels of motivation

The problem of low levels of motivation commonly exhibited by students studying ill-defined and indeterminate domains can be addressed primarily by the use of an

overarching scenario within which the courses are delivered. In the case of the manufacturing systems course, which was the focus of this study, this scenario was established using a comprehensive and coherent narrative to tell the ‘story’ of Team Detectors Limited. The creation of a comprehensively detailed virtual enterprise allowed those factors to flourish which are identified in the literature as motivational drivers. These are the provision of an authentic context, and the use of authentic content in the cognitively challenging tasks to be completed. These factors raise the level of situational interest which is a prime element in promoting increased levels of commitment and motivation in students (Chen et al., 2001: 383-400, Hidi and Anderson, 1992: 215 - 238, Hidi et al., 1998: 249-446, Mitchell, 1993: 424-436).

Intrinsic and extrinsic rewards are also strong motivators and when both are present they can reinforce each other (Hidi and Harackiewicz, 2000: 151-179). Intrinsic motivation, or interest in the subject, for its own sake, was promoted by the immersive nature of the intervention, for example, the option to run multiple production line simulations and plot many solutions to the scheduling problem in a bid ‘to beat your best score’. Extrinsic motivation, or action for reward, was promoted by ensuring that the tasks were ‘do-able’, that there was not one, perfect answer and that good marks were available as long as the student applied some logic and thought to their proposed solution. The tasks were designed to cover several levels of cognition so that all students could achieve at least some of each task regardless of their position on the Perry scale of intellectual development. The best and most comprehensive solutions required an evaluation of alternate solutions and encouraged students to move from a dualistic stance towards a more relativistic one.

It was noted that the lecturer can also influence the level of motivation possessed by students. A lecturer displaying McGregor’s Theory Y behaviour and encouraging and supporting students in their endeavours will have a marked positive effect on motivation and student performance (Markwell, 2004: 323-325).

The following sample of quotes from students in the semi-structured interviews indicated the success of the attempt to increase levels of motivation:

“With the high-level of internal assessment it helped to make it interesting. I was more motivated to play with the software we did.”

“Yes it definitely motivated you” (the tasks/assessments).

“It’s weird. At home I kept thinking that if I have one more go at Arena I might get a better result, flow. It’s a bit addictive”.

6.3.4.2. Levels of engagement

As with the problem of motivation, a solution to the issue of low levels of student engagement in courses in primarily complex and ill-defined domains can be found by the provision of an authentic context created by a rich and realistic narrative. The use of virtual manufacturing staff in the intervention made the learning experience more personalised and had the effect of making the material more engaging. The use of carefully selected, short and relevant videos (e.g. about Gentrac Limited), illustrating manufacturing engineers and operators dealing with real-life issues, also increased the personalisation of the learning tool.

Another factor in increasing levels of student engagement was their relatively long-term contact with the scenario and the virtual enterprise (one semester). This is in contrast to the examples of ‘virtual factory’ type interventions and simulated production processes discovered in the literature which typically are of short duration. Their limited contact times are a characteristic which militates against students becoming personally absorbed in the scenarios they attempt to create.

The following sample quotes from students in the semi-structured interviews are illustrative of the levels of engagement and personalisation achieved:

“I have to deliver this detector by the due date or I will be in trouble”

“The videos and film gave a personal touch to the course that I haven’t met before.”

“Those guys at the lean place [Gentrac Limited] were really enthusiastic, I liked them, I don’t think it was for the cameras.”

“You know, I really wanted to help her out [operator in ergonomics task video], silly because it’s only an exercise.”

6.3.4.3. Conception of integration

Students commonly have difficulty understanding how the topics presented to them in a complex domain relate to each other. This is a serious problem in areas such as manufacturing systems which contain a large number of fundamental topics across a

range of disciplines. These range from the purely technical (machine production rates and reliability) through to IT (data collection and analysis) and sociological (human performance, learning curves, etc.). It is important that students appreciate the integrated nature of such manufacturing or management systems, as small changes in one part of the system can affect other parts, often in unexpected ways. An appreciation of this quality of integration is important also in that it increases the student's understanding of what material is being presented and why.

This common problem, of students not understanding how course topics mesh together, was tackled by applying authentic tasks in an authentic context with the tasks linked in a coherent, logical and chronological sequence. The topic material which was covered mapped the 'story' being told about the virtual enterprise throughout the duration of the course; from establishing a new plant layout through to providing finished products, on time, to customers. The concept of integration was reinforced by the tasks presented, which were also mapped to the narrative and topic presentation. Biggs (2007) suggests that a demonstrated connection between course topics also increases levels of motivation.

Some sample interview comments on this issue were:

"The way the jobs all interconnected, that was good."

"What I liked was the way the tasks joined together. That made them make sense, yes. ...much better than ordinary lecture test questions."

"The jobs joined together, like a story. Also I liked the often, little assessments."

6.3.4.4. Acceptance of indeterminacy

The immersive characteristics of the virtual enterprise appeared, from student feedback, to have dealt with the problem of indeterminacy by the appropriate design of a series of well-connected tasks presented to the students. The data given to students had a designed-in level of indeterminacy and the requirements for student outputs were also left somewhat open. For example, in determining the throughput of their manufacturing system in an Arena® simulation the students were required to attempt to achieve a reasonable output but no specific figure was given as a target. The results from the application of the Learning Environment Preferences instrument indicated that the

largest cohort of students (34%) were in Perry position 3 (Early Multiplicity) whilst 25% were in transition between positions 2 and 3, and 27% were in transition between 3 and 4. Thus, the majority of students were prepared for some uncertainty in the solutions to problems. However, this acceptance is not unconditional and students at these levels generally still believe that with enough time and effort a ‘correct’ answer can be found but, in the meantime, everyone is entitled to their own opinions. Those students in transition from positions 2 to 3 are beginning to relinquish their view that uncertainty exists but, still believe that there is only one correct answer to a problem. Those students in transition from position 3 to position 4 are beginning to realise that uncertainty is common and unavoidable, but still, somewhere, some authority knows the ‘right’ answer.

The level of indeterminacy in the tasks was set such that they would pose a challenge to students in these Perry positions but not too much of a challenge, what Perry called, “the pleasure zone”. There is no formulaic way of setting this level. Settings were established by the use of Bloom’s taxonomy together with practitioner experience and by making any required amendments to the tasks during the design-based research process of intervention iteration and modification. Care was taken not to make the tasks appear too difficult to students unfamiliar with manufacturing systems and their topics. Making the tasks too difficult would have had a detrimental effect on motivation since students are more motivated by tasks in which they expect to do well. Students felt that the tasks simulated real-life jobs accurately and this perceived relevance of the material to future careers was also a motivator.

“The task of the facility layout was good as it was hard to know if you should treat it as a typical university project or think outside the box and have a risk of not doing what was wanted.”

“We had to think about what was relevant, like in a real job.”

6.3.5. Research Question 2

The following sections describe the findings in relation to the problems contained in research question 2.

What specific educational theories and pedagogical strategies would effectively form the framework for this improvement?

What was required for this study was a well-founded pedagogical strategy that would assist with resolving the issues outlined in research question 1, be compatible with the researcher's own ontological and epistemological views, and compatible also with the design-based research methodology adopted for the study. Following the literature review, and a study of the work done by a number of researchers, a situated learning framework was adopted (Brown et al., 1989: 32-42, Lave and Wenger, 1991, Herrington and Oliver, 1995: 253-262, Standen and Herrington, 1997, Cognition and Technology Group at Vanderbilt, 1993: 52-70, Herrington and Oliver, 2000). Situated learning has its antecedents in the social learning theories of Bandura (1989: 1-60) and Vygotsky (1978) and was used to assist student understanding of the topics through the application of knowledge within the context of the practices of manufacturing engineering (the Community of Practice). Most classroom activities lack this contextual characteristic.

An important feature of situated learning methods is the role of collaborative learning which, in the context of his study, meant the use of student teams for some of the tasks.

The use of this framework, which they appreciated, gave students the chance to attack problems together. There was very little concern about the possibility that a team member might be a 'freeloader' and not carry their fair share of the workload. There was even less concern about the possibility of intra-team personality clashes. These relaxed attitudes to teamwork, and jointly prepared responses to assignments, by the third year engineering students, the subjects of this inquiry, is in contrast to the views of Year Two engineering students. Formal and informal feedback from many cohorts of second year students in team-based design projects has indicated a much more suspicious, sometimes even hostile, attitude to collaboration. The concerns expressed in design courses include worries about 'freeloaders', the allocation of marks, team dynamics, and sometimes, for larger assignments, the logistical problems of arranging 'out of hours' team meetings.

By the second semester of Year Three of the degree most of these fears have been allayed. It is believed that this is because the students will have had sufficient experience of team-based work to cease to worry about the possibility of 'unfair' marking and difficult team logistics. At this stage of their journey through the degree

course they know the members of their cohort very well and, as far as team members who are shirkers are concerned, students seem sufficiently confident in their personal skills to be able to deal with anyone who is not pulling their weight. Students at this stage of the degree course also seem to be more aware of the preponderance of collaborative work carried out in the workplace by professional engineers and of the importance placed by employers on good teamworking skills.

6.3.6. Other Findings

The following sections describe the findings in relation to other issues addressed.

6.3.6.1. Compatibility with student learning styles

Felder (2005: 57-72), and Riding and Douglas (1993: 297-307) say that the more clearly educators understand the differences between students in their attitudes to learning and their responses to different classroom environments and instructional methods, the more likely they are to meet their students' differing learning needs. As a result, surveys were carried out to determine students' learning styles using the Kolb Learning Style Inventory. This instrument and Kolb's learning cycle and learning style theory were described in detail in Chapter 2, Section 2.7.15. The results of the final surveys are recorded in Chapter 5, Section 5.3.5.5. The surveys indicated that approximately 49% of students were convergers, 29% were assimilators, with 11% accommodators and 11% divergers. These percentages are typical of undergraduate engineering classes.

Convergers typically ask 'What can I do?' and prefer the learning cycle steps of abstract conceptualisation and active experimentation. Assimilators (reflective observation and abstract conceptualisation) typically ask 'what does it mean?' and like to be involved in activities that include creative problem solving, teamwork and brainstorming.

Convergers and assimilators are suited to learning activities such as analysis, model building and theory construction.

Accommodators (active experimentation and concrete experience) ask 'how can I do it?' and prefer practical exercises, relevant videos, simulations, case studies and projects. Divergers (concrete experience and reflective observation) ask 'What is it?' and are also suited to learning activities involving teamwork, observation and creative problem solving. Felder (2005: 57-72) advises practitioners that they should provide

guidance and feedback for convergers, allow the accommodators to discover things for themselves, and act as an expert for the simulators and a motivator for the divergers.

Pre-course and post-course surveys indicated that students' learning styles were predominantly stable over the period covered. The teaching intervention was designed to ensure that the needs of the predominant learning style group, convergers, was met whilst also meeting the needs of students with other learning styles. The virtual enterprise intervention was designed to ensure that these preferences were catered for by the use of models and simulations, problem solving, projects (tasks) and the use of teams in problem analysis and solution. Divergers and accommodators, minority groups in engineering cohorts, are disadvantaged by the traditional didactic teaching styles in most engineering courses and the un-contextualised and closed-ended problems given. The intervention addressed this issue with the use of open-ended tasks which allowed for some creativity in the solutions offered.

A comparison between learning styles and academic performance, as measured by both students' coursework marks and total course marks, found no correlation between learning styles and academic achievement. Thus it was determined that the immersive teaching intervention was of benefit to students, with no discrimination, at all levels of achievement within this third year course.

6.3.6.2. Appropriate level of task indeterminacy

The intervention was also designed in accordance with the suggestions of Felder and Brent (2004) that the tasks present a challenge to the intellectual beliefs that characterise a student's current intellectual position. This was achieved by setting the level of indeterminacy at a level requiring some acceptance of, or movement toward, relativism following an assessment of students' level of intellectual development (as measured by Moore's Learning Environment Preferences instrument). The assessed positions were consistent with typical student positions as described in the literature.

As far as their levels of intellectual development were concerned, students in the manufacturing systems cohorts were predominantly in position 3 or in transition between positions 3 and 4 on the Perry scale and the teaching intervention was designed with this transition position in mind. Thus, it was designed so that students moving from a dualist to a relativist position would be challenged with tasks which involved ill-

defined problems and multiple, perhaps non-optimal, solutions. A comparison between positions on the Perry scale of intellectual development found no correlation between position, scale and academic performance as measured by students' coursework marks and total marks. Thus the team detectors intervention does not appear to discriminate against, or to be of less utility, for students above or below this targeted position.

6.4. Conclusions

The outcome of the investigation into the first part (a) of research question 2 was that the situated learning model was a successful alternative to the traditional didactic, teacher-led, lecture/tutorial method and, in addition, was more congruent than traditional delivery with diverger and accommodator preferred learning styles. Most of the students were motivated by the virtual organisation scenario and the authentic seeming nature of the tasks. Students report a 'willing suspension of disbelief' an effect which facilitated their immersion into the virtual factory narrative and scenario and which provided increased levels of motivation.

This success was indicated by the results obtained from student questionnaires. When asked if the simulated industry scenario had added interest a positive response was received from 68.6% of respondents, 66.6% thought that the scenario had added relevancy and 78.4% thought that the concept of industry-based scenarios should be extended to other engineering topics, see Table 5-5.

The rating (out of 10) of the manufacturing system course as given by the university's annual survey rose from 3.8, prior to the application of the intervention, to 7 at its completion.

6.5. Implications for Teaching & Action

The computer-based virtual enterprise teaching intervention created as a result of this research study has been shown to improve the delivery of complex ill-defined and primarily non-quantitative domains in engineering such as manufacturing systems. This intervention, packaged on a DVD with printed manual, is available for use by other practitioners. The pedagogically centred course design methodology, also developed as a result of this research, will enable other practitioners to adapt and adopt the intervention to suit their own particular circumstances and courses. Use of the

methodology will save time in the development of new applications and ensure that important features of the intervention, such as its location within a situated learning framework, are maintained.

For example, by application of the methodology and adaptation of the tasks, practitioners will be able to modify the intervention for use with other complex ill-defined courses in areas such as engineering and operations management, finance and ethics for engineers, etc. The intervention can be easily modified to incorporate additional topics and tasks such as the simulation of CNC machining operations.

By utilising readily available industry-standard software for simulation, scheduling and workstation analysis the intervention avoids the use of in-house developed software. Experience shows that in-house software generally is expensive in terms of the time required to develop and maintain and does not assist with the authentic and immersive aims of the intervention. As pointed out by Ehrmann (2000: 40-49) and by Earle (2002: 5-13), quoted by Albirini (2007: 227-236), the modification of most computer-based courseware is a challenge for lecturers who wish to adapt it for their courses and their students. If adaptation is allowed by the program at all it is often difficult and time-consuming.

It is hoped that this intervention, as published on DVD will encourage the use of computer technology in the teaching of manufacturing systems, operations management and engineering management by presenting educators with a teaching package almost 'ready to go' and thus save the time required for developing a package from scratch. The Team Detectors virtual enterprise is flexible and easy to modify and practitioners may change it as they wish.

To facilitate the most effective adoption of the intervention, and the design methodology that accompanies it, the intervention was designed to include Rodger's (2003) recommendations to encourage the, sometimes hesitant, take-up of technology by practitioners. That is, it was designed to present a clear advantage over existing pedagogical methods in the field, to be compatible with existing methods, to simplify the design of new courses and to assist in improving existing courses. The intervention package is largely self-contained and can be trialled and its effectiveness observed before full-scale implementation.

The DVD package includes the full coding for the company's web site, copies of the student tasks and copies of the industrial software used for simulation, ergonomic analysis and scheduling. This industrial software is freely available to practitioners and students. The Arena® modelling and simulation software is an evaluation version with full functionality with the exception of a limit of 150 entities available within a model at any one time. This restriction does not inhibit the building and simulation of models of sufficient complexity for the desired teaching outcomes. The Preactor® scheduling software is also freely available and is fully functional with the exception of the range of dates which are available, these are fixed to commence at 1st January, 2000. In practice this does not decrease the value of the software as a teaching tool.

The results of this research project may be added to the existing body of work in this area and to the record of interventions discussed in the Literature Review. Using the format adopted in Table 2-1 the intervention is tabulated as follows:

Table 6-1: The Addition of the Current Research to Existing Intervention

Date	Title	Author/s	Institution	Brief Description	Comments
2009	Understanding the factors that support the effective application of multimedia in the study of complex non-quantitative concepts in manufacturing undergraduate courses	Martin McCarthy	University of Auckland	This intervention uses a virtual manufacturing enterprise, supported by a rich and coherent narrative and a substantial amount of supporting 'company' documentation, to provide an immersive experience to students of manufacturing systems. The intervention is based upon a situated learning framework and primarily constructivist pedagogy.	Simulates a full manufacturing enterprise and includes student tasks in the topics of plant layout, ergonomics, production system simulation and production scheduling

6.6. New Design Methodology

In the generation of a teaching intervention for use with courses in ill-defined domains, a methodology was created for application to the design of courses in other domains such as manufacturing, engineering management and operations management.

The methodology has at its core a virtual enterprise supported by a rich and coherent narrative. In addition to the enterprise itself other 'players' may be incorporated to

influence the simulation of the virtual operation. These may be outside the narrative envelope, such as suppliers and customers, or inside the narrative story affecting the enterprise with, for example, legislation, taxes and local by-laws. The virtual environment envelope may thus be modified as shown in Figure 6-1 below.

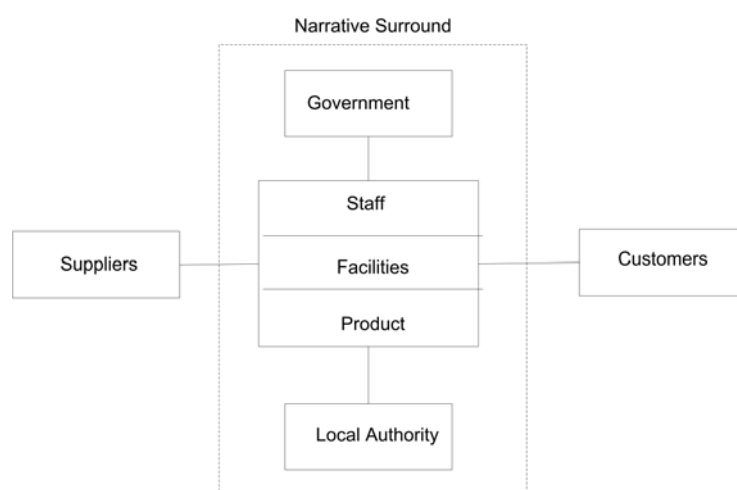


Figure 6-1: The Virtual Enterprise Environment

The methodology is based upon a modular process involving the preparation of learning outcomes, informed by Bloom's taxonomy which, when allied to the knowledge content for each topic, are applied to the relevant task. The template designed for this procedure is shown in Table 4-4. Also input into the task is tacit knowledge on the part of the student and his or her colleagues, and data and task instructions from the enterprise. Assessment takes place immediately after the task with feedback, in the form of data and of new knowledge, informing both the next task in the sequence and enabling a reassessment of the decisions made in the previous one. See Figure 6-2.

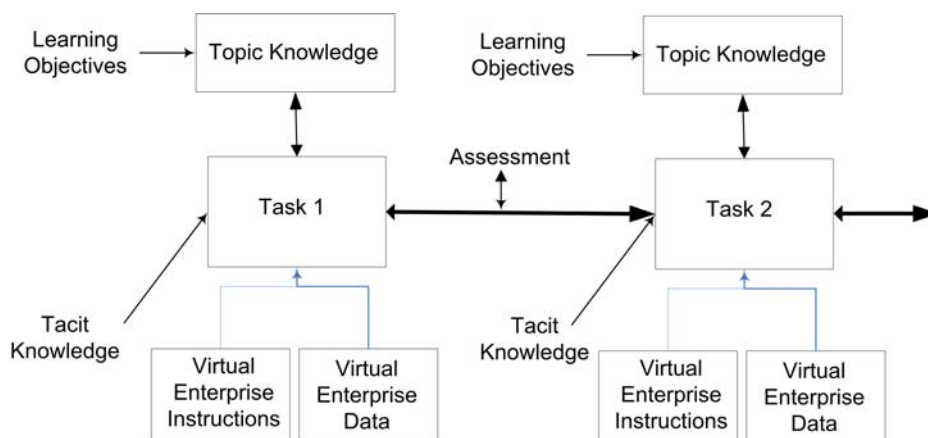


Figure 6-2: Modular Intervention Design Process

The steps in the methodology are shown in Figure 6-3 below:

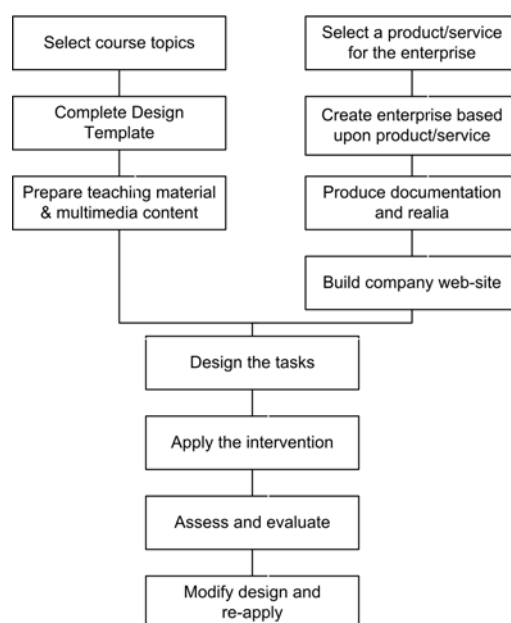


Figure 6-3: Intervention Design Flow Chart

6.7. Recommendations for Future Research

One area for further development is that of increasing peer collaboration and intra and inter student team communications. Further developments in this area would bolster the virtual factory intervention's adherence to the authentic learning framework adopted for its delivery and the framework's requirement for effective student collaboration (Reeves et al., 2002: 562-567). Research by Artemeva and Logie (2002: 62-85) shows that with appropriate coaching and guidance undergraduate students can create valuable feedback for their colleagues. This is useful in reinforcing understanding of the course topics and provides students with useful critical analysis and commenting expertise for use later in industry or in postgraduate studies.

Provided that ethical approval could be obtained it would be useful to research the connection, if any, between a student's response to the teaching intervention and their learning style and position on the Perry scale. As long as the limitations of these instruments were recognised this might suggest beneficial changes to the design and presentation of the intervention.

Further developments could include the use of expanded manufacturing system models to simulate not only the movement and processing of materials but of the company's

flow of data and information. Currently only the flow of materials in the production process is considered, however, since the flow of data, represents the control system for the production process its omission may lead to the poor decisions being made as the result of simulation runs. It would be useful to model the total control system and its behaviour.

Research by psychologists has suggested that students are able to recall information more easily if recall is attempted when they are situated in the same context in which the information was first learned (Thalheimer, 2003), (Brown, 2004). This finding warrants further investigation. Students may be disadvantaged if they are expected to recall information in a 'sterile' exam context which was learned in a social and situated learning environment. There is a disconnection between the original learning context and that of the examination. It would be valuable if we could understand more completely how students think and learn, and how they make decisions about ill-defined and complex problems.

Further research programmes can heed Herrington's (2006: 3164-3173) calls for more research on authentic learning approaches. She writes that the publication of new design-based research studies would make an important contribution "to understanding how such authentic learning environments function and succeed in real educational contexts" (p.3169). Shortridge (2002) also maintains that there is a requirement for further examples of 'student engaging' applications of computer-based education in engineering.

6.8. Concluding Remarks

It is hoped that the result of this current research will be to provide a tool to assist engineering educators to incorporate computer-based multimedia and immersive elements into their manufacturing systems and engineering/operations management courses. The intervention created will give them a proven and successful virtual environment to use as a 'workbench' which they may adapt to meet their own requirements. The methodology developed as result of this research offers a modular approach to the design of interventions in ill-defined domains when used, in conjunction with the situated learning framework, the design template, and a quality narrative supported by appropriate documentation and realia.

7. References

- Anon, 2006. *How students learn*. [Online]. Ohio State University. Available: http://ucat.osu.edu/read/teaching/how_students_learn/learn.html. [1st February 2006].
- Abrahamson, C. E. 1998. Storytelling as a pedagogical tool in higher education, *Education*. 118(3): 12. (accessed 19th September 2003, from questia database).
- Agogino, A. M., Song, S. & Hey, J. 2006. Triangulation of indicators of successful student design teams. *International Journal of Engineering Education* 22(3): 617-625. Available: http://www.ijee.dit.ie.ezproxy.auckland.ac.nz/latestissues/Vol22-3/23_ijee1772.pdf.
- Ahmed, M. S., Baskin, N. L., Tonkay, G. L. & Zimmers, E. W. 2003. E-learning activities for teaching manufacturing systems. Paper presented to *International Conference on Engineering Education*, Valencia, 21st-25th July. Available: <http://www.ineer.org/events/icee2003/proceedings/pdf/5516.pdf>. [20th May 2005].
- Akker, J. V. 2006. Introducing educational design research, in *Educational design research*, edited by Akker, J. V., Gravemeijer, K., McKenney, S. & Nieveen, N. London: Routledge.
- Albirini, A. 2007. The crisis of educational technology, and the prospect of reinventing education. *Educational Technology & Society*. 10 (1): 227-236. Available: http://www.ifets.info/journals/10_1/20.pdf [23rd Jun 2008].
- Ambron, S. & Hooper, K. 1988. *Interactive multimedia*. Redmond, WA: Microsoft Press.
- Anderson, J. R., Reder, L. M. & Simon, H. A. 2000. *Applications and misapplications of cognitive psychology to mathematics education*. [Online]. ACT-R. Available: <http://act-r.psy.cmu.edu/papers/38/SDOC4129.pdf>. [21st June 2004].
- Anderson, L. W., Krathwohl, D. R. & Bloom, B. 2001. *Taxonomy for learning, teaching and assessing. A revision of bloom's taxonomy of educational objectives*. New York: Longmans.
- Anderson, T. 2004. Practice guided by research in providing effective student support services. Paper presented to *Third EDEN Research Workshop - Supporting the learner in distance education and e-learning*, Oldenburg, Germany, 4th-6th March. Available: <http://www.col.org/colweb/site/pid/2959>. [14/1/2008].

- Angen, M. J. 2000. Evaluating interpretive inquiry: Reviewing the validity debate and opening the dialogue, *Qualitative Health Research*. 10(3): 378-395. (accessed 20th June 2006, from Sage database).
- Anon. 2006. *Suspension of disbelief*. [Online]. Wikipedia. Available: http://en.wikipedia.org/wiki/Suspension_of_disbelief. [1/12/2006].
- Artemeva, N. & Logi, S. 2002. Introducing engineering students to intellectual teamwork: The teaching and practice of peer feedback in the professional communication classroom. *Language and Learning across the Disciplines*. 6 (1): 62-85. Available: <http://tc.eserver.org/22979.html> [23rd May 2008].
- Ashley, K. D., Chi, M., Pinkus, R. & Moore, J. D. 2004. *Modeling learning to reason with cases in engineering ethics: A test domain for intelligent assistance*. Grant application to National Science Fund, USA.
- Babbie, E., R. 2007. *The basics of social research*. Sydney: Thomson/Wadsworth.
- Bandura, A. 1977. *Social learning theory*. Englewood Cliffs, N.J.: Prentice Hall.
- Bandura, A. 1989. Social cognitive theory, in *Annals of child development*, edited by Vasta, R. Greenwich, CT: JAI Press.
- Bandura, A. & Walters, R. 1963. *Social learning and personality development*. New York: Holt, Rinehart and Winston.
- Barab, S. A. & Squire, K. D. 2004. Design-based research: Putting a stake in the ground, *Journal of the Learning Sciences*. 13(1): 1-14. (accessed from Informaworld database).
- Barab, S. A., Squire, K. D. & Dueber, W. 2000. A co-evolutionary model for supporting the emergence of authenticity, *Educational Technology Research and Development*. 48(2): 37-62. (accessed from SpringerLink database).
- Baranauskas, M. C. C., Neto, N. G. C. & Borges, M. A. F. 2000. Gaming at work: A learning environment for synchronized manufacturing, *Computer Applications in Engineering Education*. 8(3-4): 162-169. (accessed 20/11/2007, from Wiley InterScience database).
- Basnet, C. 1996. Report: *Simulation games in production management education*, University of Waikato, Hamilton, NZ.
- Basnet, C. 2001. *An experiential learning system for production planning and control*. [Online]. University of Waikato. Available: <http://www.mngt.waikato.ac.nz/cbasnet/PMSimulation/MRPSIM.htm>. [12th May 2008].
- Baxter Magolda, M. B. 2001. A constructivist revision of the measure of epistemological reflection, *Journal of College Student Development*. 42(6). (accessed from Project MUSE database).

- Bearman, M. 1997. Narratives and cases: Implications for computer-based education. Paper presented to *ASCLITE '97*, Curtin University of Technology Western Australia, 7th-11th December. Available: <http://www.ascilite.org.au/conferences/perth97/papers/Bearman/Bearman.html>. [14/8/04].
- Becker, H. J. 2000. Findings from the teaching, learning, and computing survey: Is Larry Cuban right? . 8 (51): Available: <http://epaa.asu.edu/epaa/v8n51/>
- Bednar, A. K. 1992. Constructivism and the technology of instruction: A conversation, in Duffy, T. M. & Jonassen, D. H. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Bednar, A. K., Cunningham, D., Duffy, T. M. & Perry, J. D. 1995. Theory into practice: How do we link?, in *Instructional technology: Past, present, and future*, edited by Anglin, G. J. 2nd Edition. Englewood, Col: Libraries Unlimited.
- Belenky, M. F., Clinchy, B. M., Goldberger, N. R. & Tarule, J. M. 1986. *Women's ways of knowing: The development of self, voice and mind*. New York: Basic Books.
- Berg, G. A. 2003. *The knowledge medium: Designing effective computer-based learning environments*. 1st Edition. Hershey: Information Science Publishers.
- Bernold, L. E., Bingham, W. L., McDonald, P. H. & Attia, T. M. 2000. Impact of holistic and learning-oriented teaching on academic success, *Journal of Engineering Education*. 89(2): 191-199. (accessed 12th November 2008, from ProQuest database).
- Biggs, J. 2007. *Teaching for quality learning at university*. 3rd Edition. Maidenhead: McGraw-Hill.
- Biggs, J. B. 1987. *Student approaches to learning and studying*. Melbourne: Australian Council for Educational Research.
- Billington, P. J. 2004. A classroom exercise to illustrate lean manufacturing pull concepts, *Decision Sciences Journal of Innovative Education*. 2(1): 71-76. (accessed from Wiley InterScience database).
- Bird, J., Morgan, C. & O'reilly, M. 2007. Exploring the tensions in educational and instructional design in Australian universities, in *Instructional design – case studies in communities of practice*, edited by Keppell, M. J. New York: Information Science Publishing.
- Bizzell, P. 1984. William Perry and liberal education, *College English*. 46: 447-454. (accessed from JSTOR database).
- Bizzocchi, J. & Woodbury, R. F. 2003. A case study in the design of interactive narrative: The subversion of the interface, *Simulation and Gaming*. 34(4): 550-568. (accessed from Sage Full Text Journal Collections database).

- Bloom, B. 1956. *Taxonomy of educational objectives: The classification of educational goals, handbook 1: Cognitive domain*. New York: David McKay Co.
- Bodner, D. A., Damrau, P. M. & Griffin, L. F. 1997. Virtual machine models for electronics assembly. Proceedings of *Deneb International Simulation Conference and Technology Showcase*, Troy, Mi. 61-66.
- Boissiere, M., Knight, J. B. & Sabot, R. H. 1985. Earnings, schooling, ability, and cognitive skills, *American Economic Review*. 75(5): 1016-1030. (accessed from JSTOR database).
- Boles, W. & Pillay, H. 2002. A study on the impact of designing computer based instruction considering preferred cognitive styles. Proceedings of *AAEE 13th Annual Conference*, Canberra, Australia. 66-71.
- Borrego, M. 2007. Conceptual difficulties experienced by trained engineers learning educational research methods, *Journal of Engineering Education*. 96(2): 91-102. (accessed from ProQuest database).
- Bowden, P., El-Zein, A. & Airey, D. 2006. Underpinning a discipline-specific ethics course. Paper presented to *13th Annual Conference of the Australian Association of Professional and Applied Ethics*, Sydney, 12th-14th June.
- Bransford, J., Brown, A. L. & Cocking, R. R. 2000. Report: *How people learn : Brain, mind, experience, and school*, National Research Council, USA, Washington, D.C.
- Brewer, W. F. 1995. To assert that essentially all human knowledge and memory is represented in terms of stories is certainly wrong, in *Knowledge and memory: The real story*, edited by Wyer, R. S. New Jersey: Lawrence Erlbaum Associates.
- Bringelson, L. S., Lyth, D. M., Reck, R. & Landeros, R. 1995. Training industrial engineers with an interfunctional computer simulation game, *Computers and Industrial Engineering*. 29(1-4): 89-92. (accessed from ScienceDirect database).
- Brooks, G. P. 1998. Perry: Fact, fiction and outcomes assessment. Paper presented to *Meeting of the Mid-Western Educational Research Association*, Chicago, Ill, 14th-17th October. Available: <http://www.eric.ed.gov/ERICWebPortal/recordDetail?accno=ED428084>. [14/12/2006].
- Brown, A. L. 1992. Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings, *Journal of the Learning Sciences*. 2(2): 141-178. (accessed from Informaworld database).
- Brown, A. L. 1994. The advancement of learning. *Educational Researcher*, 23(8): 4-12.
- Brown, A. L. & Campione, J. C. 1994. Guided discovery in a community of learners., in *Classroom lessons: Integrating cognitive theory and classroom practice*, edited by McGilly, K. Cambridge, MA: MIT Press.

- Brown, G. 2004. *How students learn* [Online]. RoutledgeFalmer Available: http://www.routledgeeducation.com/resources/pdf/how_to_learn.pdf. [14th March 2005].
- Brown, J. S., Collins, A. & Duguid, P. 1989. Situated cognition and the culture of learning. *Educational Researcher*, 18(1): 32-42.
- Bruner, J. 1990. *Acts of meaning*. Cambridge, MA: Harvard University Press.
- Bruner, J. S. 1960. *The process of education*. Cambridge, Ma: Harvard University Press.
- Bruner, J. S. 1961. The act of discovery. *Harvard Educational Review*, 31(1): 21-32.
- Bruner, J. S. 1966. *Toward a theory of instruction*. Cambridge, Ma: Harvard University Press.
- Bruner, J. S. 1996. *The culture of education*. Cambridge, Ma: Harvard University Press.
- Bruning, R. H., Schraw, G. J. & Ronning, R. R. 1995. *Cognitive psychology and instruction*. Englewood Cliffs, New Jersey: Prentice Hall.
- Burton, L. J. & Nelson, L. J. 2006. The relationships between personality, approaches to learning and academic success in first-year psychology distance education students. Paper presented to *Higher Education Research and Development Society, 2006 International Conference*, Perth, 10th-12th July. Available: <http://www.herdsa.org.au/wp-content/uploads/conference/2006/Burton.PDF>.
- Bütün, E. 2005. Teaching genetic algorithms in electrical engineering education: A problem-based learning approach, *International Journal of Electrical Engineering Education*. 42(3): 223-233. (accessed from IngentaConnect database).
- Caine, R. N. & Caine, G. 2005. *12 brain/mind learning principles in action : The fieldbook for making connections, teaching, and the human brain*. Thousand Oaks, Ca: Corwin Press.
- Cairncross, S. & Mannion, M. 2001. Interactive multimedia and learning: Realizing the benefits, *Innovations in Education & Teaching International*. 38(2): 156-164. (accessed from IngentaConnect database).
- Chen, A., Darst, P. W. & Pangrazi, R. P. 2001. An examination of situational interest and its sources. *British Journal of Educational Psychology*, 71(3): 383-400.
- Chen, J. H. & Wu, Y. S. 2008. Dispatching rule in a fuzzy rule knowledge-based system for automated manufacturing. *International Journal of the Computer, the Internet and Management*, 16(1): 53-60. Available: www.journal.au.edu/ijcim/2008/jan2008/ijcim-v16_1_7.pdf (accessed 1/3/2008).
- Chi, X., Pepper, M. P. & Spedding, T. A. 2004. A web-based virtual factory for teaching industrial statistics. *Proceedings of 2004 Winter Simulation Conference*, Washington, D.C. 2103-2106.

- Clancey, W. J. 1995. A tutorial on situated learning. Proceedings of *International Conference on Computers and Education*, Taiwan. 49-79.
- Clark, R. E. & Craig, T. G. 1992. Research and theory on multi-media learning effects, in *Interactive multimedia learning environments: Human factors and technical considerations on design issues*, edited by Giardina, M. New York: Springer-Verlag.
- Clegg, S. 2005. Evidence-based practice in educational research: A critical realist critique of systematic review. *British Journal of Sociology of Education*, 26(3): 415-428.
- Cobb, P., Disessa, A., Lehrer, R. & Schauble, L. 2003. Design experiments in educational research. *Educational Researcher*, 32(1): 9-13.
- Coffield, F., Moseley, D. & Ecclestone, K. 2004. *Learning styles and pedagogy in post-16 learning*. London: Learning and Skills Research Centre.
- Cognition and Technology Group at Vanderbilt. 1993. Anchored instruction and situated cognition revisited. *Educational Technology*, 33(3): 52-70.
- Collins, A. 1992. Towards a design science of education, in *New directions in educational technology*, edited by Scanlon, E. & O'Shea, T. Berlin: Springer.
- Cox, J. F. & Walker, E. D. 2004. The poker chip game: A multi-product, multi-customer, multi-echelon, stochastic supply chain network useful for teaching the impacts of pull versus push inventory policies on link and chain performance, *Transactions on Education*. 6(3): 3-19. (accessed from IEEE Xplore database).
- Cronje, T. & Coll, R. K. 2008. Student perceptions of higher education science and engineering learning communities, *Research in Science & Technological Education*. 26(3): 295-309. (accessed from Informaworld database).
- Cuban, L. 2001. *Oversold and underused, computers in the classroom*. Cambridge, Ma: Harvard University Press.
- Culver, R. S. 1996. Teaching and learning as a change process. Proceedings of *26th Annual Frontiers in Education Conference*, Salt Lake City, Utah. 1287-1290.
- Culver, R. S. & Hackos, J. T. 1982. Perry's model of intellectual development. *Engineering Education*, 73(December): 221-226.
- Curry, L. 1983. An organization of learning styles theory and constructs. Paper presented to *67th Annual Meeting of the American Educational Research Association*, Montreal, 11th-15th April. Available: <http://eric.ed.gov/ERICWebPortal/recordDetail?accno=ED235185>.
- Curry, L. 1987. Report: *Integrating concepts of cognitive learning style: A review with attention to psychometric standards*, Canadian College of Health Science Executives, Ottawa.

- Curry, L. 1990. A critique of the research on learning styles, *Educational Leadership*. 48(2): 50-56. (accessed from EBSCOhost database).
- Curzon, L. B. 2004. *Teaching in further education: An outline of principles and practice*. 6th Edition. London: Continuum.
- Das, J. P. 1988. *Simultaneous-successive processing and planning*. New York: Plenum Press.
- Dawes, J. G. 2008. Do data characteristics change according to the number of scale points used?, *International Journal of Market Research*. 50(1): 61-77. (accessed from EBSCO Business Source Premier database).
- Debello, T. C. 1990. Comparison of eleven major learning styles models: Variables, appropriate populations, validity of instrumentation and the research behind them, *Journal of Reading, Writing, and Learning Disabilities*. 6: 203-222. (accessed 1st June 2008, from Informaworld database).
- Denning, S. 2001. *The springboard : How storytelling ignites action in knowledge-era organizations*. Boston: Butterworth-Heinemann.
- Deshpande, A. A. & Huang, S. H. 2009. Simulation games in engineering education: A state of the art review, *Computer Applications in Engineering Education*. (accessed from Wiley InterScience database).
- Design-Based Research Collective. 2003. Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 32(1): 5-8.
- Dessouky, M. M. 2000. May 2000. A methodology for developing a web-based factory simulator for manufacturing education. *HE Transactions*, 2001(33): 167-180.
- Diseth, A. 2003. Personality and approaches to learning as predictors of academic achievement, *European Journal of Personality*. 17(143-155). (accessed from Wiley InterScience database).
- Diseth, A. & Martinsen, O. 2003. Approaches to learning, cognitive styles, and motives as predictors of academic achievement, *Educational Psychology*. 23: 195-207. (accessed from Informaworld database).
- Donaldson, S. I. 2008. *What counts as credible evidence in applied research and evaluation practice?* Newbury Park, CA: SAGE Publications.
- Driscoll, M. P. 2005. *Psychology of learning for instruction*. 3rd Edition. Boston: Allyn and Bacon.
- Dunkle, M. E., Schraw, G. J. & Bendixen, L. D. 1995. Cognitive processes in well-defined and ill-defined problem solving. Paper presented to *Annual Meeting of the American Educational Research Association*, San Francisco, 18th-22nd April.

- Dym, C. L., Agogino, A. M., Ozgur, E., Frey, D. D. & Leifer, L. J. 2005. Engineering design thinking, teaching, and learning, *Journal of Engineering Education*. 94(1): 103-120. (accessed from Proquest database).
- Earle, R. 2002. The integration of instructional technology into public education: Promises and challenges. *Educational Technology*, 42(1): 5-13.
- Eccles, J. S. & Wigfield, A. 2002. Motivational beliefs, values and goals, *Annual Review of Psychology*. 53: 109-132. (accessed 23rd July 2004, from ProQuest database).
- Edelson, D. C. 2002. What we learn when we engage in design, *Journal of the Learning Sciences*. 11(1). (accessed from Informaworld database).
- Education and Skills Committee. 2005. Report: *Report on the UK e-University*, House of Commons, London.
- Ehrmann, S. C. 2000. *Technology and revolution in education: Ending the cycle of failure*. [Online]. Teaching, Learning and Technology Group. Available: http://www.tltgroup.org/resources/V_Cycle_of_Failure.html. [12th August 2005].
- El-Mounayri, H., Wasfy, T., Fernandez, E. & Peters, J. 2008. Innovative online course using an integrated virtual reality based e-learning tool with course management tool, in *Innovative techniques in instruction technology, e-learning, e-assessment, and education*, edited by Iskander, M. New York: Springer Science+Business Media B. V.
- Elgood, C. 1996. *Using management games*. 2nd Edition. Aldershot, Hants: Gower.
- Entwistle, N. 1981. *Styles of learning and teaching*. Chichester: Wiley.
- Entwistle, N. & Ramsden, P. 1983. *Understanding student learning*. London: Croom Helm.
- Epstein, R. 1996. *Creativity games for trainers: A handbook of group activities for jumpstarting workplace creativity*. New York: McGraw-Hill.
- Ertmer, P. A. & Newby, T. J. 1993. Behaviourism, cognitivism, constructivism: Comparing critical features from an instructional design perspective, *Performance Improvement Quarterly*. 6(4): 50-70. (accessed from Wiley InterScience database).
- Fang, N., Cook, R. & Hauser, K. 2007. Integrating lean systems education into manufacturing course curriculum via interdisciplinary collaboration. Paper presented to 2007 American Society for Engineering Education Annual Conference and Exposition, Honolulu, 23th-27th June. Available: http://www.icee.usm.edu/ICEE/conferences/asee2007/papers/516_INTEGRATING_LEAN_SYSTEMS_EDUCATION_INTO_.pdf.
- Felder, R. & Brent, R. 2000. Is technology a friend of foe of learning. *Chemical Engineering Education*, 34(4): 326-327.

- Felder, R. & Brent, R. 2005. Understanding student differences, *Journal of Engineering Education*. 94(1): 57-72. (accessed from ProQuest database).
- Felder, R. M. 2004. The intellectual development of science and engineering students: Part 1 models and challenges, *Journal of Engineering Education*. 93(4): 289. (accessed 19th March 2006, from ProQuest database).
- Felder, R. M. & Henriques, E. R. 1995. Learning and teaching styles in foreign and second language education *Foreign Language Annals*, 28(1): 21-31.
- Felder, R. M., Stice, J. E. & Rugarcia, A. 2000. The future of engineering education vi. Making reform happen *Chemical Engineering Education*, 34(3): 208-215. Available: www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Quartet6.pdf.
- Ferguson, E. S. 1992. *Engineering and the mind's eye*. Cambridge, Ma.: MIT Press.
- Firestone, W. A. 1987. Meaning in method: The rhetoric of quantitative and qualitative research. *Educational Researcher*, 16(7): 16-21.
- Fitch, P. & Culver, R. S. 1984. Educational activities to stimulate intellectual development in Perry's scheme. Proceedings of *ASEE Annual Conference*, Washington, DC. 712-717.
- Fontana, A. & Frey, J. H. 2000. The interview: From structured questions to negotiated text, in *The handbook of qualitative research*, edited by Denzin, N. K. & Lincoln, Y. S. 2 Edition. Thousand Oaks, Calif: Sage Publications.
- Fowler, L., McGill, D., Armarego, J. & Alle, M. 2002. Quantitative learning conversations: Constructivism and its application to learning in an engineering environment. Paper presented to *HERDSA 2002*, Perth, 7th-10th July. Available: <http://www.ecu.edu.au/conferences/herdsa/main/papers/ref/pdf/Fowler.pdf>.
- Gagne, R. M. 1987. *Instructional technology: Foundations*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Gagné, R. M. 1970. *The conditions of learning*. 2nd Edition. London: Holt, Rinehart & Winston.
- Gall, I. & Ginsburg, L. 1994. The role of beliefs and attitudes in learning statistics: Towards an assessment framework. *Journal of Statistics Education*, 2(2). Available: <http://www.amstat.org/publications/jse/v2n2/gal.html>. (accessed 23rd August 2003).
- Gardner, H. 1993. *Multiple intelligences: The theory in practice*. New York: Basic Books.
- Garrison, D. R. & Anderson, T. 2003. *E-learning in the 21st century : A framework for research and practice*. London: RoutledgeFalmer.

- Gijbels, D., Dochy, F., Van Den Bossche, P. & Segers, M. 2005. Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research*, 75(1): 27-61.
- Good, T. L. & Brophy, J. E. 1990. *Educational psychology: A realistic approach*. White Plains, NY: Longman.
- Goodyear, P. 2000. Environments for lifelong learning, in *Integrated and holistic perspectives on learning, instruction and technology*, edited by Spector, J. M. & Anderson, T. M. Boston: Kluwer Academic Publishers.
- Graesser, A. & Ottati, V. 1995. Why stories? Some evidence, questions, and challenges, in *Knowledge and memory: The real story*, edited by Wyer, R. New Jersey: Lawrence Erlbaum Associates.
- Gredler, M. E. 2004. Games and simulations and their relationships to learning, in *Handbook of research on educational communications technology*, edited by Jonassen, D. 2 Edition. Mahwah, N.J: Lawrence Erlbaum Associates.
- Greeno, J. 1989. A perspective on thinking. *American Psychologist*, 44(2): 134-141.
- Gregorc, A. F. 1979. Learning/teaching styles: Potent forces behind them, *Educational Leadership*. 36(4): 234-237. (accessed from EBSCOhost database).
- Groves, M. 2005. Problem-based learning and learning approach: Is there a relationship?, *Advances in Health Sciences Education*. 10(4): 315 - 326. (accessed from SpringerLink database).
- Guba, E. G. & Lincoln, Y. S. 1989. *Fourth generation evaluation*. Newbury Park, CA: Sage Publications.
- Guba, E. G. & Lincoln, Y. S. 1994. Competing paradigms in qualitative research, in *Handbook of qualitative research*, edited by Denzin, N. & Lincoln, Y. 1st Edition. Thousand Oaks, CA: SAGE Publications Limited.
- Gunter, G., Kenny, R. & Vick, E. H. 2006. *A case for a formal design paradigm for serious games*. [Online]. Miami University Center for Interactive Media Studies. Available:
<http://www.units.muohio.edu/codeconference/papers/papers/Gunter%20Kenny%20Vick%20paper.pdf>. [2nd March 2007].
- Hadavi, K., Hsu, W., Chen, T. & Lee, C. 1992. *An architecture for real time distributed scheduling*. AAAI Press/MIT Press. Available:
www.asap.cs.nott.ac.uk/projects/ds/Multi-Agent%20Scheduling%20in%20Manufacturing%20Systems. [2/3/2008].
- Hake, R. R. 2005. *Design-based research: A primer for physics-education researchers*. [Online]. American Journal of Physics. Available:
<http://www.physics.indiana.edu/~hake/DBR-AJP-6.pdf>. [2nd April 2006].

- Hargrove, S. K. & Dahleh, M. 2006. Using multi-media courseware to enhance active student learning in the classroom. Paper presented to *ASEE Annual Conference and Exposition*, Chicago, Illinois, 18th-21st June
Available: <http://soa.asee.org/paper/conference/paper-view.cfm?id=1648>.
- Hawk, T. F. & Shah, A. J. 2007. Using learning style instruments to enhance student learning, *Decision Sciences Journal of Innovative Education*. 5(1): 1-19. (accessed from Wiley InterScience database).
- Henkel, M. 2000. *Academic identities and policy change in higher education*. London: Jessica Kingsley.
- Hergenhahn, R. & Olson, M. H. 2005. *An introduction to theories of learning*. 7th Edition. New Jersey: Prentice Hall.
- Herrington, J. 2006. Authentic e-learning in higher education: Design principles for authentic learning environments and tasks. Proceedings of *World Conference on e-Learning in Corporate, Government, Healthcare, and Higher Education*, Chesapeake, VA. 3164-3173.
- Herrington, J. & Oliver, O. 1995. Critical characteristics of situated learning: Implications for the instructional design of multimedia. Proceedings of *ASCILITE'95 Learning with Technology*, Melbourne. 253-262.
- Herrington, J. & Oliver, R. 2000. Towards a new tradition of online instruction: Using situated learning theory to design web-based units. Paper presented to *ASCILITE 2000*, Coffs Harbour, Australia, 9th-14th December. Available: http://www.editlib.org/d/8912/proceeding_8912.pdf. [26th July 2004].
- Herrington, J., Oliver, R. & Reeves, T. 2003. Cognitive realism in online authentic learning environments. Proceedings of *World Conference on Educational Multimedia, Hypermedia and Telecommunications*, Chesapeake, VA. 2115-2121.
- Herrington, J. & Standen, P. 2000. Moving from an instructivist to a constructivist multimedia learning environment, *Journal of Educational Multimedia and Hypermedia* 9(3). (accessed from Expanded Academic database).
- Hertel, J. P. 2002. *Using simulations to promote learning in higher education: An introduction*. 1st Edition. Sterling, VA: Stylus Publishing.
- Heywood, J. 1995. Towards the improvement of quality in engineering education. Paper presented to *Frontiers in Education Conference*, Atlanta, 1st-4th November. Available: <http://doi.ieeeecomputersociety.org/10.1109/FIE.1995.483023>.
- Hidi, S. & Anderson, V. 1992. Situational interest and its impact on reading and expository writing, in *The role of interest in learning and development*, edited by Renninger, A. Hillsdale, NJ Erlbaum.

- Hidi, S., Berndorff, D. & Ainley, M. 1998. Children's argument writing, interest and self-efficacy: An intervention study *Learning and Instruction*. 12(4): 249-446. (accessed from ScienceDirect database).
- Hidi, S. & Harackiewicz, J. M. 2000. Motivating the academically unmotivated: A critical issue for the 21st century. *Review of Educational Research*, 70(2): 151-179.
- Higgins, N., Sullivan, H., Harper-Marinick, M. & López, C. 1989. Perspectives on educational technology research and development, *Educational Technology Research and Development*. 37(1): 7-18. (accessed from SpringerLink database).
- Hiles, D. 1999. Paradigms lost - paradigms regained. Paper presented to *18th International Human Science Conference*, Sheffield, UK., 26th-29th July. Available: <http://www.psy.dmu.ac.uk/drhiles/Paradigms%20Lost.htm>. [12/5/2002].
- Hirst, D., Brooks, C. & Riddle, M. 2005. Courseware design and development program: Providing professional development and project experience. Proceedings of *21st ASCILITE Conference*, Perth. 387-394.
- Hofer, B. K. & Pintrich, P. R. 1997. The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning, *Review of Educational Research*. 67(1): 88-140. (accessed 10th April, 2006, from Sage database).
- Houghton, W. 2004. *Learning and teaching theory for engineering academics: Deep and surface approaches to learning*. [Online]. Available: <http://www.engsc.ac.uk/er/theory/learning.asp>. [15th March 2006].
- Hsieh, S. & Hsieh, P. 2001. Intelligent tutoring system authoring tool for manufacturing engineering education. *International Journal of Engineering Education*, 17(6): 569-579. Available: <http://www.ijee.dit.ie.ezproxy.auckland.ac.nz/articles/Vol17-6/IJEE1202.pdf>.
- Hung, I. W., Choi, A. C. & Chan, J. S. 2003. An integrated problem-based learning model for engineering education. *International Journal of Engineering Education*, 19(5): 734-737. Available: <http://www.ijee.dit.ie.ezproxy.auckland.ac.nz/latestissues/Vol19-5/IJEE1448.pdf>. (accessed 20/7/2008).
- Hunter, J. E. & Hunter, R. F. 1984. Validity and utility of alternative predictors of job performance. *Psychological Bulletin*, 96(1): 72-98.
- Ikenberry, S. O. 1999. The university and the information age, in *Challenges facing higher education at the millennium*, edited by Hirsch, W. Z. & Weber, L. E. Phoenix, AZ: Oryx Press.
- Institution of Professional Engineers New Zealand. 2009a. Report: *Graduate competence profile for professional engineers*, Institution of Professional Engineers New Zealand,

- Institution of Professional Engineers New Zealand. 2009b. Report: *Requirements for initial academic education for professional engineers*, Institution of Professional Engineers New Zealand, Wellington.
- Irish, R. 1999. Engineering thinking: Using Benjamin bloom and William Perry to design assignments. *Language and Learning Across the Disciplines*, 2(3): 83-100. Available: <http://users.ece.utexas.edu/~friedric/wac2.pdf#page=85>. (accessed 3/3/2008).
- Jackson, P. L. & Muckstadt, J. A. 2000. *Course materials for manufacturing system design*. [Online]. Cornell University. Available: <http://www.orie.cornell.edu/~jackson.asee.html>. [13 October 2004].
- Jacobs, R. 2007. *Manufacturing - the great crashshoot*. [Online]. Kelley School of Business, Indiana University Available: www.pom.edu/p429/Slides/Great%20Manufacturing%20Crashshoot.doc [12th March 2008].
- Jehng, J., Johnson, S. D. & Anderson, R. C. 1993. Schooling and students' epistemological beliefs about learning, *Contemporary Educational Psychology*. 18(1): 23-35. (accessed from ScienceDirect database).
- Jensen, D. & Wood, K. 2000. Incorporating learning styles to enhance mechanical engineering curricula by restructuring courses, increasing hands-on activities, & improving team dynamics. Paper presented to *ASME Annual Conference*, Orlando, FL, 5th-10th November. Available: <http://files.asme.org/asmeorg/Governance/Honors/1094.pdf>.
- Jensen, D., Wood, K. & Wood, J. 2000. Report: *Enhancing mechanical engineering curriculum through the use of hands-on activities, interactive multimedia and tools to improve team dynamics*, U.S. Air Force Academy, Colorado Springs, Co.
- Jensen, K., Gallacher, I., Hussain, S. & Mcleod, J. 1997. An interactive telecommunications business game for strategic exploration. *Proceedings of 15th International System Dynamics Conference: Systems Approach to Learning and Education into the 21st Century*, Istanbul. 491-494.
- Johnson, D. W. & Johnson, R. T. 1989. *Cooperation and competition: Theory and research*. Edina, MN: Interaction Book Company.
- Jonassen, D., Cemusca, D. & Lonas, G. 2007. Constructivism and instructional design: The emergence of the learning sciences and design research, in *Trends and issues in instructional design and technology*, edited by Reiser, R. A. & Dempsey, J. V. 2nd Edition. Upper Saddle River, NJ: Pearson.
- Jonassen, D., Strobel, J. & B, L. C. 2006. Everyday problem solving in engineering: Lessons for engineering educators, *Journal of Engineering Education*. 95(2): 139-151. (accessed from Proquest database).

- Jonassen, D. H. 2000. Toward a design theory of problem solving, *Educational Technology Research and Development*. 48(4): 63-85. (accessed from SpringerLink database).
- Jones, S. E. 2007. Reflections on the lecture: Outmoded medium or instrument of inspiration?, *Journal of Further and Higher Education*. 31(4): 397-406. (accessed from Informaworld database).
- Kayes, C. D. 2005. Internal validity and reliability of Kolb's learning style inventory, version 3 (1999), *Journal of Business and Psychology*. 20(2). (accessed from SpringerLink database).
- Kearsley, G. 2009. *The theory into practice database*. [Online]. Greg Kearsley. Available: <http://www.gwu.edu/~tip/>. [12th March 2009].
- Keefe, J. W. & Ferrell, B. G. 1990. Developing a defensible learning style paradigm, *Educational Leadership*. 48(2): 57-61. (accessed from EBSCOhost database).
- Keijzer, F. 2005. Theoretical behaviorism meets embodied cognition. Two theoretical analyses of behavior, *Philosophical Psychology*. 18(1): 123-143. (accessed 24th July 2007, from Informaworld database).
- Keller, J. 1983. Motivational design of instruction, in *Instructional-design theories and models*, edited by Reigeluth, C. M. Hillsdale, N.J: Lawrence Erlbaum Associates.
- Kelly, G. C. 2002. A powerful virtual learning environment. Paper presented to *Australian Society for Computers in Learning in Tertiary Education*, Auckland, 8th-11th December. Available: <http://www.ascilite.org.au/conferences/auckland02/proceedings/papers/176.pdf>. [1/4/2006].
- Kelton, W. D., Sadowski, R. P. & Sturrock, D. T. 2007. *Simulation with Arena*. 4th Edition. Boston: McGraw Hill.
- Kember, D. & Gow, L. 1989. A model of student approaches to learning encompassing ways to influence and change approaches, *Instructional Science*. 18: 263-288. (accessed from SpringerLink database).
- Kesavadas, T., Lefort, L. & Ernzer, M. 1999. Interactive virtual factory for shop floor design using cellular manufacturing concepts. (accessed 25/02/2003, from database).
- King, P. M. & Kitchener, K. S. 1994. *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco: Jossey-Bass.
- Kirby, J. R. 1988. Style, strategy and skill in reading, in *Learning strategies and learning styles*, edited by Schmeck, R. R. New York: Plenum press.

- Kline, W. A. 2005. A course in manufacturing systems with simulation. Paper presented to *American Society for Engineering Education Annual Conference*, Portland, Oregon, 12th-15th June. Available: <http://soa.asee.org/paper/conference/paper-view.cfm?id=21573>. [20/5/2007].
- Kolb, D. A. 1981. Learning styles and disciplinary differences, in *The modern American college. Responding to the new realities of diverse students and a changing society*, edited by Chickering, A. W. San Francisco: Jossey-Bass.
- Kolb, D. A. 1984. *Experiential learning: Experience as the source of learning and development*. New Jersey: Prentice-Hall.
- Kosslyn, S. M. 1980. *Image and mind*. Cambridge, Ma: Harvard University Press.
- Latham, G. P. & Ernst, C. T. 2006. Keys to motivating tomorrow's workforce, *Human Resource Management Review* 16: 181-198. (accessed from ScienceDirect database).
- Laurillard, D. 2001. The role of universities in a digital age. Paper presented to *Forum for the Future of Universities*, Aspen, Colorado, USA, September. Available: <http://net.educause.edu/ir/library/pdf/ffp0205s.pdf>.
- Laurillard, D. 2002. *Rethinking university teaching: A conversational framework for the effective use of learning technologies*. 2nd Edition. New York: RoutledgeFalmer.
- Lave, J. 1988. *Cognition in practice: Mind, mathematics, and culture in everyday life*. New York: Cambridge University Press.
- Lave, J. & Wenger, E. 1991. *Situated learning. Legitimate peripheral participation*. Cambridge: University of Cambridge Press.
- Leblanc, S. & Hogg, J. 2006. Storytelling in knowledge management: An effective tool for uncovering tacit knowledge
Paper presented to *STC Atlanta Currents Conference*, Atlanta, USA, 24th-25th March. Available: <http://www.stcatlanta.org/currents06/proceedings/leblanc.pdf>.
- Leifer, L. 1995. Evaluating project-based-learning education. Proceedings of *International Workshop on the Evaluation of Engineering Education*, Osaka, Japan.
- Lindeque, P. & Kruger, P. S. 1988. The design of a microcomputer based simulator for production management training
Computers and Industrial Engineering. 14(1): 53-62. (accessed from ScienceDirect database).
- Lizzio, A., Wilson, K. & Simons, R. 2002. University students' perceptions of the learning environment and academic outcomes: Implications for theory and practice. *Studies in Higher Education*, 27(1): 27-52.

- Lutz, S. & Huitt, W. 2004. Connecting cognitive development and constructivism: Implications from theory for instruction and assessment. *Constructivism in the Human Sciences*, 9(1): 67-90. Available: <http://chiron.valdosta.edu/whuitt/brilstar/chapters/cogdev.doc>. (accessed 2/1/2007).
- Lyke, J., A. & Kelaheer-Young, A. J. 2006. Cognition in context: Students' perceptions of classroom goal structures and reported cognitive strategy use in the college classroom, *Research in Higher Education*. 47(4): 477-490. (accessed from SpringerLink database).
- Lynch, F. C., Alevan, V., Ashley, K. D. & Pinkwart, N. 2006. Defining “ill-defined domains”; a literature survey. Paper presented to *Eighth International Conference on Intelligent Tutoring Systems*, Taiwan, 26th-30th June, 2006. Available: <http://www.cs.cmu.edu/~hypoform/its-workshop/>. [11/1/2009].
- Maier, F. H. 2000. What are we talking about - a taxonomy of computer simulations to support learning, *System Dynamics Review*. 16(2): 135-148. (accessed from Wiley InterScience database).
- Markwell, J. 2004. The human side of science education, *Biochemistry and Molecular Biology Education*. 32(5): 323-325. (accessed from ScienceDirect database).
- Marra, R. M., Palmer, B. & Litzinger, T. A. 2000. The effects of a first-year engineering design course on student intellectual development as measured by the Perry scheme, *Journal of Engineering Education*. 89(1): 39-46. (accessed from ProQuest database).
- Marshall, J. C. & Merritt, S. L. 1986. Reliability and construct validity of the learning style questionnaire. *Educational and Psychological Measurement*, 46 (1): 257-262.
- Marton, F. & Säljö, R. 1976. On qualitative differences in learning — 2: Outcome as a function of the learner's conception of the task. *British Journal of Educational Psychology*, 46: 115-127.
- Maslow, A. 1954. *Motivation and personality*. New York: Harper & Bros.
- Mathison, S. 1988. Why triangulate? *Educational Researcher*, 17(3): 13-17.
- Mayer, R. E. 2001. *Multimedia learning*. Cambridge, UK: Cambridge University Press.
- Mayer, R. E. 2005. The failure of educational research to impact educational practice: Six obstacles to educational reform, in *Empirical methods for evaluating educational interventions*, edited by Phye, G. D., Robinson, D. H. & Levin, J. R. Burlington: Elsevier Academic Press.
- McCarthy, M. 2004. An immersive, intranet assisted approach to teaching manufacturing systems students. Paper presented to *International Engineering Education Conference*, Wolverhampton, UK, 31st May-2nd June.

- McCarthy, M., Seidel, R. & Tedford, D. 2002. Developments in project and multimedia based learning in manufacturing systems. Paper presented to *Australasian Association for Engineering Education*, Canberra, 30th Sept-2nd Oct.
- McClelland, D. & Johnstone, E. 1984. *Learning to achieve*. Glenview, Illinois: Scott, Foreman & Co.
- McConnell, S. 2001. *Transferring your passion for teaching to the online environment: A five step instructional development model*. [Online]. Colorado State University. Available: <http://www.usq.edu.au/electpub/e-jist/docs/old/vol4no1/2001docs/pdf/mconnell.pdf>. [28 May 2002].
- McDaniel, T. R. 2004. *A software-based knowledge management system using narrative texts*. Doctoral Thesis. University of Central Florida. Available: <http://portal.acm.org/citation.cfm?id=1087626&coll=GUIDE&dl=GUIDE&CFID=43471720&CFTOKEN=33059059>. [20th March 2008].
- McDonald, J. 2007. The changing role of an instructional designer in the implementation of blended learning at an Australian university, in *Instructional design case studies in communities of practice* edited by Keppell, M. J. Hershey, New York: Information Science Publishing.
- McGilly, K. 1994. *Classroom lessons: Integrating cognitive theory and classroom practice*. Cambridge, Ma: MIT Press.
- McGregor, D. 1960. *The human side of enterprise*. New York: McGraw-Hill.
- McMahon, R. E. 2005. Teaching information technology using the Perry stages. *Proceedings of 6th Conference On Information Technology Education*, Newark, NJ. 277-281.
- Mentkowski, M., Moeser, M. & Strait, M. 1983. Report: *Using the Perry scheme of intellectual and ethical development as a college outcomes measure: A process and criteria for judging student performance*, Alverno College, Milwaukee.
- Mergel, B. 2001. *Instructional design and learning theory*. [Online]. University of Saskatchewan. Available: www.usask.ca/education/coursework/802papers/mergel/brenda.htm [25 June 2002].
- Merriam, S. B. 2002. *Qualitative research in practice : Examples for discussion and analysis*. San Francisco: Jossey-Bass.
- Merrill, M. D., Drake, L., Lacey, M. J. & Pratt, J. 1996. Reclaiming instructional design. *Educational Technology*, 36(5): 5-7.
- Millard, D. L. 2000. Interactive learning modules for electrical engineering education. *Proceedings of 50th Electronic Components and Technology Conference*, Las Vegas. 1042-1047.

- Miller, G. A. & Gildea, P. M. 1987. How children learn words. *Scientific American*, 257(3): 94-99.
- Miller, R. L., Olds, B. M. & Pavelich, M. J. 2000. *Using intelligent computer technology to measure the intellectual development of engineering students*. [Online]. Colorado School of Mines, Golden, Colorado. Available: http://www.ifets.info/journals/10_2/ets_10_2.pdf. [12th December 2006].
- Minsky, M. 1995. Steps to artificial intelligence, in *Computation and intelligence, collected readings*, edited by Luger, G. F. Menlo Park, CA: Association for the Advancement of Artificial Intelligence.
- Mishkin, M. & Appenzellert, T. 1987. The anatomy of memory. *Scientific American*, 256(6): 80-89.
- Mitchell, M. 1993. Situational interest: Its multifaceted structure in the secondary school mathematics classroom, *Journal of Educational Psychology*. 85: 424-436. (accessed from Ovid database).
- Montgomery, S. & Groat, L. 2001. *Student learning styles and their implications for teaching*. Michigan: Center for Research on Learning and Teaching, University of Michigan.
- Moore, W. S. 1989. The learning environment preferences: Exploring the construct validity of an objective measure of the Perry scheme of intellectual development, *Journal of College Student Development*. 30(6): 504-514. (accessed from Project MUSE database).
- Moore, W. S. 2000. *The learning environment preferences: An instrument manual*. Olympia, Washington: Center for the Study of Intellectual Development.
- Moore, W. S. 2002. Understanding learning in a postmodern world, in *Personal epistemology : The psychology of beliefs about knowledge and knowing*, edited by Hofer, B. K. & Pintrich, P. R. Mahwah, N.J: Lawrence Erlbaum Associates.
- Muther, R. 1955. *Practical plant layout*. New York: McGraw-Hill.
- Nelson, T. F., Shoup, R. & Kuh, G. D. 2005. Deep learning and college outcomes: Do fields of study differ? Paper presented to *Annual Meeting of the Association for Institutional Research*, San Diego, May 29-June 1st. Available: http://nsse.iub.edu/pdf/conference_presentations/2005/AIR2005DeepLearning-PRES.pdf. [12/11/2007].
- Netherwood, G. 1996. Using a tutorial simulation in manufacturing planning & control. Paper presented to *13th Annual Conference of the Australian Society of Computers in Tertiary Education*., University of South Australia, Adelaide, 2nd-4th December. Available: <http://www.ascilite.org.au/conferences/adelaide96/papers/16.html>. [21/5/2003].

- Neuman, W. L. 2000. *Social research methods: Qualitative and quantitative approaches*. 4th Edition. Boston: Allyn and Bacon.
- Neuman, W. L. 2006. *Social research methods: Qualitative and quantitative approaches*. 6th Edition. Boston: Pearson.
- Newman, D. 1990. Opportunities for research on the organizational impact of school computers. *Educational Researcher*, 19(3): 8-13.
- Nicholson, T. A. J. 2000. Integrating management and engineering perspectives through interactive learning. Proceedings of *5th International Workshop on Games in Production Management*, Karlsruhe, Germany.
- Noguera, J. H. & Watson, E. F. 2004. Effectiveness of using an enterprise system to teach process-centered concepts in business education, *Journal of Enterprise Information Management*. 17(1): 56-74. (accessed from Emerald Management Xtra database).
- Nulty, D. D. & Barrett, M. A. 1986. Transitions in students' learning styles. *Studies in Higher Education*, 21: 333-345.
- Nutley, S., Walter, I. & Davies, H. T. O. 2003. *From knowing to doing: A framework for understanding the evidence-into-practice agenda*. Sage Publications. Available: <http://evi.sagepub.com/cgi/content/abstract/9/2/125>. [21/4/2008].
- O'Donnell, A. M. 2004. A commentary on design research, *Educational Psychologist*. 39(4): 255-260. (accessed from Informaworld database).
- Ochs, E. & Capps, L. 2001. *Living narrative: Creating lives in everyday storytelling*. Cambridge, Ma: Harvard University Press.
- Olds, B. M., Miller, R. L. & Pavelich, M. J. 2000. Measuring the intellectual development of students using intelligent assessment software. Paper presented to *30th Frontiers in Education Conference*, Kansas City, MO, 18th-21st October. Available: <http://www.ineer.org/Events/ICEE2000/Proceedings/papers/WC8-3.pdf>. [14/12/2006].
- Ong, S. K. M., Kand, M. & Mannan, M. A. 2002. A web-based interactive teaching package in manufacturing engineering. Paper presented to *International Conference on Engineering Education*, UK, 18th-22nd August. Available: <http://nich.dgtu.donetsk.ua/konf/konf7/o163.pdf>.
- Oppenheimer, T. 1997. The computer delusion. *The Atlantic Monthly*, 280 (1): 45-62.
- Oppenheimer, T. 2003. *The flickering mind*. New York: Random House.
- Ozelkan, E. C. & Galambosi, A. 2008. Lampshade game for teaching lean manufacturing. Paper presented to *2008 Industrial engineering Research Conference*, Vancouver, BC, 17th-21st May. Available: <http://sag.sagepub.com/cgi/rapidpdf/1046878109334331v1.pdf>.

- Page-Bucci, H. *The value of likert scales in measuring attitudes of online learners*. [Online]. Page-Bucci, H. Available: <http://www.hkadesigns.co.uk/websites/msc/remel/likert.htm>. [15 January 2004].
- Paiget, J. 2001. *The psychology of intelligence* 2nd Edition. London: Routledge.
- Palmer, B., Marra, R. M. & Litzinger, T. A. 2000. A longitudinal study of intellectual development of engineering students: What really counts in our curriculum? Paper presented to *30th Frontiers in Education Conference*, Kansas City, Mo, 18th-21st October. Available: <http://fie-conference.org/fie2000/papers/1060.pdf>.
- Paske, R. 1990. Hypermedia: A brief history and progress report, *Technological Horizons In Education*. 18(1). (accessed from Expanded Academic database).
- Paulsen, M. B. & Wells, C. T. 1998. Domain differences in the epistemological beliefs of college students, *Research in Higher Education*. 39(4): 365-384. (accessed from SpringerLink database).
- Pavelich, M. J. & Moore, W. S. 1993. Measuring maturing rates of engineering students using the Perry model. *Proceedings of Frontiers in Education Conference*, 451-455.
- Perry, W. G. 1970. *Forms of intellectual and ethical development in the college years: A scheme*. New York: Holt, Rinehart and Winston.
- Perry, W. G. 1981. Cognitive and ethical growth: The making of meaning, in *The modern American college*, edited by Chickering, A. W. 1st Edition. San Francisco: Jossey-Bass.
- Pillay, H. 1998. An investigation of the effect of individual cognitive preferences on learning through computer-based instruction, *Educational Psychology*. 18(2): 171-182. (accessed from Informaworld database).
- Plowman, L. 1996. Narrative, linearity and interactivity: Making sense of interactive multimedia, *British Journal of Educational Technology*. 27(2): 92-105. (accessed from Wiley InterScience database).
- Plowman, L. 1998. Getting sidetracked: Cognitive overload, narrative, and interactive learning environments and the role of the teacher. *Proceedings of UNESCO/Open University International Colloquium*, Milton Keynes.
- Plowman, L. & Luckin, R. 1999. Designing multimedia for learning: Narrative guidance and narrative construction *Proceedings of SIGCHI Conference on Human Factors in Computing Systems*, Pittsburgh, PA. 310-317.
- Polkinghorne, D. 1988. *Narrative knowing and the human sciences*. Albany: State University of New York Press.
- Porter, L. W. 1961. A study of perceived need satisfaction in bottom and middle management jobs. *Journal of Applied Psychology*, 45: 1-10.

- Prensky, M. 2001. Digital natives, digital immigrants, *On the Horizon*. 9(5). (accessed from Emerald Management Xtra database).
- Radcliffe, D. F. & Jolly, L. 2003. Dilemmas in framing research studies in engineering education. Proceedings of *2003 American Society for Engineering Education Annual Conference & Exposition*, Nashville, Ten. 1-21.
- Rafe, G. E., Needy, K. L., Bidanda, B. & Schmidt, T. M. 2001. Delivering continuous manufacturing education and training via an Internet-based distributed virtual laboratory. Proceedings of *31st ASEE/IEEE Frontiers in Education Conference*, Reno, Nevada. 18-23.
- Raju, P. K. & Sankar, C. S. 2000. Evaluation of an engineering education courseware across different campuses. Paper presented to *30th ASEE/IEE Frontiers in Education Annual Conference*, Kansas City, 18th-21st October. Available: http://www.liteecases.com/lcm/catalog/case_studies/0/della-steam-plant/8/. [1/4/2006].
- Ramsden, P. 2003. *Learning to teach in higher education*. 2nd Edition. London: RoutledgeFalmer.
- Ramsden, P. & Entwistle, N. J. 1981. Effects of academic departments on students' approaches to studying. *British Journal of Educational Psychology*, 51: 368-383. (accessed 1st April 2005).
- Randel, J. M., Morris, B., Wetzel, C. D. & Whitehill, B. V. 1992. The effectiveness of games for educational purposes: A review of recent research, *Simulation and Gaming*. 23(3). (accessed from Sage Full Text Journal Collections database).
- Reeves, T. C. 2000. Enhancing the worth of instructional technology research through "Design experiments" And other development research strategies. Paper presented to *International Perspectives on Instructional Technology Research for the 21st Century*, New Orleans, USA, 27th April. Available: <http://it.coe.uga.edu/~treeves/AERA2000Reeves.pdf>.
- Reeves, T. C. 2002. Storm clouds on the digital horizon. Paper presented to *ASCILITE 2002*, Auckland, 8th-11th December. Available: http://www.ascilite.org.au/conferences/auckland02/proceedings/papers/key_reeves.pdf.
- Reeves, T. C. 2006. Design research from the technology perspective, in *Educational design research*, edited by Akker, J. V., Gravemeijer, K., McKenney, S. & Nieveen, N. London: Routledge.
- Reeves, T. C., Herrington, J. & Oliver, R. 2002. Authentic activities and online learning. Proceedings of *Higher Education Research and Development Society of Australasia*, Perth. 562-567.

- Reeves, T. C., Herrington, J. & Oliver, R. 2004. A development research agenda for online collaborative learning, *Educational Technology Research and Development*. 52(4): 53-65. (accessed 20th Sept 2005, from SpringerLink database).
- Regan, M. & Sheppard, S. D. 1996. Interactive multimedia courseware and hands-on learning experience: An assessment study. *ASEE Journal of Engineering Education*, 85(2): 123-130.
- Resnick, L. 1987. Learning in school and out. *Educational Researcher*, 16(9): 13-20.
- Richey, R. C. 2000. *The legacy of Robert Gagné*. Clearinghouse on Information & Technology. Available: <http://www.eric.ed.gov/ERICWebPortal/contentdelivery/servlet/ERICServlet?accno=ED445674>. [24/11/2007].
- Richey, R. C., Klein, J. D. & Nelson, W. A. 2003. Development research: Studies of instructional design and development, in *Handbook of research for educational communications and technology*, edited by Jonassen, D. H. 2nd Edition. Mahwah, NJ: Lawrence Erlbaum Associates.
- Rickel, J. & Dessouky, M. 2003 A web-based simulation environment for manufacturing education. Paper presented to *International Conference on Artificial Intelligence in Education*, Sydney, 20th-24th July. Available: <http://www.isi.edu/~shaw/publications/aied03.pdf>.
- Riding, R. & Cheema, I. 1991. Cognitive styles - an overview and integration, *Educational Psychology*. 11(3): 193-215. (accessed from Informaworld database).
- Riding, R. & Douglas, G. 1993. The effect of cognitive style and mode of presentation on learning performance. *British Journal of Educational Psychology*, 63: 297-307.
- Roblyer, M. D. 2006. *Integrating educational technology into teaching*. 4th Edition. Upper Saddle River, N.J: Pearson/Merrill Prentice Hall.
- Rogers, E., M. 2003. *Diffusion of innovations*. 5th Edition. New York: Free Press.
- Rogoff, B. & Lave, J. 1984. *Everyday cognition: Its development in social context*. Cambridge, MA: Harvard University press.
- Ronen, S. 2001. Self-actualization versus collectualization: Implications for motivation theories, in *Work motivation in the context of a globalizing economy* edited by Erez, M., Klenbeck, U. & Thierry, H. K. Hillsdale, N J Lawrence Erlbaum.
- Ross, S. M. & Morrison, G. R. 2004. Experimental research methods, in *Handbook of research on educational communications and technology*, edited by Jonassen, D. 2nd Edition. New Jersey: Lawrence Erlbaum Assoc.
- Rossiter, D. & Rossiter, A. 2006. Applications of online pedagogy to a first year blended learning module using a vle. Paper presented to *International Conference on*

- Innovation, Good Practice and Research in Engineering Education*, Liverpool, UK, 24th-26th July. Available: <http://www.ee2006.info/docs/20.pdf>. [25/11/2007].
- Säljö, R. 1979. Report: *Learning in the learner's perspective: 1 some commonplace misconceptions*, Institute of Education, University of Gothenburg, Gothenburg.
- Salomon, G. 1991. Transcending the qualitative-quantitative debate: The analytic and systemic approaches to educational research. *Educational Researcher*, 20(6): 10-18.
- Sanderson, A. C., Millard, D., Rosenberger, T., Slattery, D., Jennings, W. & Sanderson, S. W. 1997. Multimedia interactive learning modules for design and manufacturing education. Paper presented to 27th *Frontiers in Education Conference*, Pittsburgh, PA, 5th-8th November. Available: <http://fie-conference.org/fie96/papers/150.pdf>. [1/3/2004].
- Savenye, W. C. & Robinson, R. S. 2004. Qualitative research issues and methods: An introduction for educational technologists, in *Handbook of research on educational communications and technology*, edited by Jonassen, D. 2 Edition. New Jersey: Lawrence Erlbaum Assoc.
- Schacter, D. L. 1996. *Searching for memory*. New York: Basic Books.
- Schank, R. & Abelson, R. 1995. Knowledge and memory: The real story, in *Knowledge and memory: The real story*, edited by Wyer, R. New Jersey: Lawrence Erlbaum Associates.
- Schiefele, U. 1991. Interest, learning and motivation., *Educational Psychologist*. 26(3&4): 299 - 323. (accessed 26th May 2004, from Informaworld database).
- Schunk, D. H. 2004. *Learning theories: An educational perspective*. 4th Edition. New Jersey: Pearson Higher Education.
- Schunk, D. H., Pintrich, P. R. & Meece, J. L. 2008. *Motivation in education: Theory, research, and applications* 3rd Edition. Upper Saddle River, N.J: Pearson/Merrill Prentice Hall.
- Schwartz, J. E. & Beichner, R. J. 1999. *Essentials of educational technology*. Boston: Allyn & Bacon
- Scriven, M. 2003. *Causation*. [Online]. Scriven. Available: <http://www.intersivity.org/lists/arn-l/archives/Nov2003/msg00312.html>. [12th May 2006].
- Seidel, R. H. A. 2001. Project-based and hypermedia supported learning approaches in manufacturing engineering. Proceedings of 17th *Australasian Association for Engineering Education Annual Conference*, Brisbane, Australia. 415-416.

- Seidel, R. H. A. & Godfrey, E. 2005. Project and team based learning: An integrated approach to engineering education. Paper presented to *ASEE/AaeE 4th Global Colloquium on Engineering Education*, Sydney, 26th-30th September. Available: <http://www.aace.com.au/conferences/papers/2005/Paper/Paper146.pdf>.
- Seidel, R. H. A. & Sitha, K. 1999. A novel hypermedia supported teaching approach. Paper presented to *2nd UICEE Annual Conference on Engineering Education*, Auckland, 10th-13th February.
- Shapiro, M. 2005. *Oversold and underused: Computers in the classroom - a review*. [Online]. The Irascible Professor. Available: <http://irascibleprofessor.com/comments-12-13-01.htm> [10th October 2005].
- Sharp, J. E. 2001. Teaching teamwork communication with Kolb learning style theory. Paper presented to *31st ASEE/IEEE Frontiers in Education Conference*, Reno, Nevada, 10th-13th October. Available: <http://fie-conference.org/fie2001/papers/1273.pdf>. [21/5/2004].
- Shavelson, R. J., Phillips, D. C., Towne, L. & Feuer, M. J. 2003. On the science of education design studies. *Educational Researcher*, 32(1): 25-28.
- Sherwood, C. 1990. Computers and higher order thinking skills. *Proceedings of WCCE, Fifth world Conference on Computers in Education*, Syney. 1081-1086.
- Shewhart, W. A. 1980. *Economic control of quality of manufactured product*. Milwaukee, Wis: American Society for Quality Control.
- Shipman, S. & Shipman, V. 1985. Cognitive style: Some conceptual, methodological and applied issues. Fall.
- Shortridge, A. 2002. *Interactive web-based instruction: What is it? And how can it be achieved?* [Online]. University of Arkansas. Available: <http://www.usq.edu.au/electpub/e-jist/docs/old/vol4no1/2001docs/pdf/shortridge.pdf>.
- Simon, D. P. 1978. Information processing theory of human problem solving, in *Handbook of learning and cognitive processes*, edited by Estes, D. Hillsdale, NJ: Lawrence Erlbaum Assoc.
- Simonson, M. R. 2003. *Teaching and learning at a distance: Foundations of distance education*. 2nd Edition. Upper Saddle River, N.J: Merrill/Prentice Hall.
- Sims, R. 2000. An interactive conundrum: Constructs of interactivity and learning theory. *Australasian Journal of Educational Technology*, 16(1): 45-57. Available: <http://www.ascilite.org.au/ajet/ajet16/sims.html>.
- Sitha, K. 1998. Report: *Development of multimedia tools for project-based teaching of industrial engineering techniques*, University of Auckland, Auckland.

- Skinner, B. F. 1968. *The technology of teaching*. New York: Appleton-Century-Crofts.
- Skinner, I., Macgill, I. & Outhred, H. 2007. Some lessons from a decade of teaching ethics to undergraduate engineering students. *Australian Journal of Professional and Applied Ethics*, 9(9): 133-144. Available:
http://www.ceem.unsw.edu.au/content/userDocs/16skinner_000.pdf.
- Smith, P. L. & Ragan, T. J. 2005. *Instructional design*. 3rd Edition. Hoboken, N.J: J. Wiley & Sons.
- Snelbecker, G. E. 1989. Contrasting and complementary approaches to instructional design, in *Instructional theories in action*, edited by Reigeluth, C. Hillsdale, NY: Lawrence Erlbaum Assoc.
- Snow, R. E. & Lohman, D. F. 1984. Toward a theory of cognitive aptitude for learning from instruction, *Journal of Educational Psychology*. 76(3): 347-376. (accessed from Ovid database).
- Sparling, D. 2002. Simulations and supply chains: Strategies for teaching supply chain management, *Supply Chain Management*. 7: 334-342. (accessed from Emerald Management Xtra database).
- Spiro, R. 1995. Report: *Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains*, Center for the Study of Reading, Champaign, IL.
- Standen, P. & Herrington, J. 1997. Acumen: An interactive multimedia simulation based on situated learning theory. Paper presented to ASCILTE '97, Perth, 7th-10th December. Available:
<http://www.ascilite.org.au/conferences/perth97/papers/Standen/Standen.html>. [20/1/2003].
- Standridge, C. R. 2001. Teaching manufacturing systems simulation in a computer aided teaching studio. Proceedings of 33rd Winter Simulation Conference Grand Rapids, MI, U.S.A. 1613-1618.
- Steiner, M. 2004. Using real-world multidisciplinary design experiences to prepare young engineers to enter today's workforce. Paper presented to *International Engineering and Product Design Education Conference*, Delft, Netherlands, 2nd-3rd September. Available:
http://www.eng.rpi.edu/mdl/images/pdf/IntlEngProdConf_Paper_Sept04.pdf [2/3/2008].
- Sterman, J. D. 2008. *Teaching takes off, flight simulators for management education: The beer game*. [Online]. Sloan School of Management MIT. Available: web.mit.edu/jsterman/www/SDG/beergame.html. [12th July 2008].
- Stokes, D. E. 1997. *Pasteur's quadrant : Basic science and technological innovation*. Washington, DC: Brookings Institution Press.

- Stokes, J. T. & Richey, R. C. 2000. Rapid prototyping methodology in action: A developmental study, *Educational Technology Research and Development*. 48(2): 63-80. (accessed from SpringerLink database).
- Stoll, C. 1999. *High tech heretic*. New York: Doubleday.
- Stone, R. 2003. *How storytelling can keep your organization on track*. [Online]. StoryWork Institute. Available: <http://www.storywork.com/orgontrack.html>. [12th March 2004].
- Stones, E. 1994. *Quality teaching: A sample of cases*. Abingdon, UK: Routledge.
- Swap, W., Leonard, D., Shields, M. & Abrams, L. 2001. Using mentoring and storytelling to transfer knowledge in the workplace, *Journal of Management Information Systems*. 18(1): 99-114. (accessed 21/2/2008, from ACM Portal database).
- Tangedahl, L. 2000. *A spreadsheet based business simulation game*. [Online]. Association for Business Simulation and Experiential Learning. Available: <http://sbaweb.wayne.edu/~absel/bkl/vol26/26da.pdf>.
- Taylor, R. & Hyde, M. 2000. Learning context and students' perceptions of context influence student learning approaches and outcomes in animal science. Paper presented to *Effective Teaching & Learning at University*, The University of Queensland 9th-10th Nov. Available: http://www.tedi.uq.edu.au/conferences/teach_conference00/papers/taylor-hyde.html.
- Tedford, J. D., Seidel, R. H. A. & Islam, M. A. 2006. Project and team-based learning - an integrated approach. Proceedings of *2nd International CDIO Conference*, Linkoping, Sweden. 1-13.
- Thalheimer, W. 2003. How simulation-like questions can replace expensive multimedia simulations. Paper presented to *19th Annual Conference on Distance Teaching and Learning*, Madison, Wisconsin, 13th-15th Sept. Available: http://www.uwex.edu/disted/conference/Resource_library/proceedings/03_15.pdf. [22/11/2008].
- Thompson, T., Heer, D., Brown, S., Traylor, R. & Fiez, T. S. 2004. Educational design, evaluation, & development of platforms for learning Paper presented to *34th ASEE/IEEE Frontiers in Education Conference*, Savannah, GA, 20th-23rd October. Available: <http://www.fie-conference.org/fie2004/papers/1644.pdf>.
- Thorndike, E. L. 1910. The contribution of psychology to education, *Journal of Educational Psychology*. 1(1): 5-12. (accessed from Ovid database).
- Thorndike, E. L. 1912. *Education: A first book*. New York: The MacMillan Company.
- Thorndike, E. L. 1932. *Fundamentals of learning*. New York: Columbia University.

- Trevelyan, J. P. 2008. *Mind the gaps: Engineering education and practice* [Online]. University of Western Australia Available: <http://www.mech.uwa.edu.au/jpt/eng-work/publications/Mind%20the%20Gaps%20draft2.pdf>. [1st December 2008].
- Van Den Akker, J. 1999. Principles and methods of design research, in *Design methodology and developmental research in education and training*, edited by Van Den Akker, J., Nieveen, N. & Branch, R. N. Netherlands: Kluwer Academic Publishers.
- Van Rossum, E. & Schenk, S. 1984. The relationship between learning conception, study strategy and learning outcome. *British Journal of Educational Psychology*, 54: 73-83.
- Vilamil-Casanova, J. & Molina, L. 1996. *An interactive guide to multimedia*. London: Prentice Hall.
- Vygotsky, L. S. 1978. *Mind and society*. Cambridge, MA: Harvard University Press.
- Wall, J. & Mcnamee, F. 2004. *The rise and fall of e-learning - what now?* [Online]. e-Learning Guru. Available: http://www.e-learningguru.com/articles/hype1_1.htm. [25th November 2007].
- Wankat, P. C., Felder, R. M., Smith, K. A. & Oreovicz, F. S. 2002. The scholarship of teaching and learning in engineering, in *Disciplinary styles in the scholarship of teaching and learning: Exploring common ground*, edited by Huber, M. T. & Morreale, S. P. Sterling, VA: Stylus Publishing.
- Wankat, P. C. & Oreovicz, F. S. 1993. *Teaching engineering*. New York: McGraw-Hill.
- Watkins, D. 2001. Correlates of approaches to learning: A cross-cultural meta-analysis, in *Perspective on thinking, learning and cognitive styles*, edited by Sternberg, R. J. & Zhang, L. F. New Jersey: Lawrence Erlbaum.
- Webb, M. W. 2003. *A definitive critique of experiential learning theory*. Doctoral Thesis. Case Western Reserve University. Available: <http://cc.ysu.edu/~mnwebb/>. [20th December 2007].
- Weiner, B. 1990. History of motivational research in education, *Journal of Educational Psychology*. 82(4): 616-622. (accessed from Ovid database).
- Weller, M. 2000. The use of narrative to provide a cohesive structure for a web based computing course. *Journal of Interactive Media in Education*, 1(1). Available: www.jime.open.ac.uk/00/1. (accessed 2/3/2003).
- West-Burnham, J. 2006. *Understanding learning*. London: Network Continuum Education.
- Willcoxson, L. & Prosser, M. 1996. Kolb's learning style inventory (1985) : Review and further study of validity and reliability. *British Journal of Educational Psychology*, 66(2): 251-261.

- Wilson, B. A. 1996. A descriptive and interpretive study: The intellectual development of adults. Paper presented to *Annual Meeting of the American Educational Research Association*, New York, 8th-12th April. Available: <http://www.eric.ed.gov/ERICWebPortal/contentdelivery/servlet/ERICServlet?accno=ED393976>.
- Wise, H. A. 1939. *Motion pictures as an aid in teaching American history*. New Haven, Conn: Yale University Press.
- Wise, J., Lee, S. H., Litzinger, T. A., Marra, R. M. & Palmer, B. 2004. A report on a four-year longitudinal study of intellectual development of engineering undergraduates, *Journal of Adult Development*. 11(2): 103-110. (accessed from SpringerLink database).
- Witkin, H., Moore, C., Gooddenough, D. & Cox, P. 1977. Field- dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research*, 47(1): 1-64.
- Wolfe, E. & Crookall, D. 1998. Developing a scientific knowledge of simulation/gaming, *Simulation & Gaming*. 29(1): 7-19. (accessed 29th May, 2005, from Sage database).
- Woolf, B. P., Poli, C. & Grosse, I. 1999. Multimedia-based active tutors - a new approach to teaching design for manufacturing. Paper presented to *4th ASME Design for Manufacturing Conference*, Las Vegas, 12th-15th Sept. Available: <http://althea.cs.umass.edu/bpw/conf/POLI%20ASME.pdf>. [1/2/2006].
- Young, M., R. 2005. The motivational effects of the classroom environment in facilitating self-regulated learning, *Journal of Marketing Education*. 27(1): 25-40. (accessed from Sage Full Text Journal Collections database).
- Zeegers, P. 2001. Approaches to learning in science: A longitudinal study. *British Journal of Educational Psychology*, 71: 115-132.
- Zeigler, B. P., Praehofer, H. & Kim, T. G. 2000. *Theory of modeling and simulation : Integrating discrete event and continuous complex dynamic systems*. San Diego: Academic Press.
- Zemsky, R. & Massy, W. 2004. *Thwarted innovation: What happened to e-learning and why*. University of Pennsylvania: The Learning Alliance for Higher Education. Available: <http://www.irhe.upenn.edu/Docs/Jun2004/ThwartedInnovation.pdf>. [12/1/2009].
- Zhong, Y. & Shirinzadeh, B. 2008. Virtual factory for manufacturing process visualization. *Complexity International* 12. Available: <http://www.complexity.org.au/ci/vol12/msid07/file.pdf>.
- Zimmerman, B. J. & Schunk, D. H. 2002. *Educational psychology: A century of contributions*. New Jersey: Lawrence Erlbaum Assoc.

List of Appendices

Note - Because the materials in these appendices are documents in their own right it has not been possible to number them to match the page numbers in this document.

Appendix A: Team Detectors Scenario

- Company Profile
- Company Background
- Site Plan
- Plant Layout
- 3D Walk-through
- Sample Web Pages

Appendix B: Team Detectors Realia

- Balance Sheet
- Personnel Register
- Capital Equipment Register

Appendix C: Team Detectors Manuf. System Documents

- Bill-of Materials Chart
- Process Flow Chart
- Bill-of Materials, interactive
- Bill-of Materials
- Bill-of Materials, flat
- Costings
- Operation Times
- Inventory

Appendix D: Ethics Document

- Participant Approval Form

Appendix E: Data Collection Instruments

- Kolb Learning Styles Inventory
- Learning Environment Preferences Instrument
- Semi-structured Interview Questions
- Student Questionnaire, iteration 4.
- Observation Chart

Appendix F: Peer Review of Research and other Publications

Publication list

Appendix G: Team Detectors Scenario

Notes on Course Development & Structure

Appendix A: Team Detectors Scenario

Company Profile
Company Background
Site Plan
Plant Layout
3D Walk-through

Appendix B: Team Detectors Realia

Bill-of Materials Chart
Process Flow Chart
Bill-of Materials, interactive
Bill-of Materials
Bill-of Materials, flat
Costings
Operation Times
Inventory

Appendix C: Team Detectors Manuf. System Documents

Bill-of Materials Chart
Process Flow Chart
Bill-of Materials, interactive
Bill-of Materials
Bill-of Materials, flat
Costings
Operation Times
Inventory

Appendix D: Ethics Document

Participant Approval Form

Appendix E: Data Collection Instruments

Kolb Learning Styles Inventory
Learning Environment Preferences Instrument
Semi-structured Interview Questions
Student Questionnaire, iteration 4
Observation Chart

Appendix F: Peer Review of Research

Peer Review of research and Other Publications

The following publications and conference presentations allowed the developments and research described in this thesis to be subject to public evaluation and comment.

Publications in refereed journals and books.

McCarthy, M., Seidel, R., Tedford, D., 'Further Developments in Project and Multimedia Based Learning in Manufacturing Systems Engineering', International Journal of Engineering Education, Vol. 20, No. 4, 2004.

Tedford, D., McCarthy, M., Seidel, R., 'A Virtual Company, Multimedia-Based Learning Environment For Teaching Students In Manufacturing', Innovations 2004, World Innovations in Engineering Education and Research, Chapter 11, INEER, Begell House Publishing, Arlington VA, USA, 2004.

McCarthy, M., 'The Application of Social Learning Theory and Communities of Practice to a Complex, Ill-Defined Domain in Engineering'. Accepted for publication in mid 2010, International Journal of Engineering Education.

Refereed Conference Proceedings

McCarthy, M., Seidel, R., Tedford, D., 'The Development of a Multimedia Based Learning Environment for Manufacturing Systems Engineering Students', International Conference on Engineering Education, 22-26 July 2003, Valencia, Spain.

Seidel, R., McCarthy, M., 'An Integrated Learning Environment for Manufacturing Systems Education', 3rd International Conference on Technology in Teaching and Learning in Higher Education, July 14-16 2003, Heidelberg, Germany.

McCarthy, M.G., Seidel, R.H.A., Tedford, J.D. 'The Use of Multimedia Techniques for Teaching Manufacturing Engineering Students', 7th Baltic Seminar on Engineering Education, Proceedings of 7th Baltic Seminar on Engineering Education, St Petersburg, September, 2003, p.141-144.

McCarthy, M., 'Learning Theory Based Application of Multimedia in Undergraduate Design Courses'. Conference on Innovation, Good Practice and Research in Engineering Education (EE2006), Liverpool, July 2006.

McCarthy, M., 'Effective teaching of manufacturing topics to undergraduate engineers utilising a novel, broadly based, interactive virtual company'. Flexible Automation and Intelligent Manufacturing conference, Limerick, 2006.

McCarthy, M., Seidel, R., Tedford, D., 'An Immersive Intranet Assisted Approach to Teaching Manufacturing Systems Students', International Engineering Education Conference, 31 May – 2 June 2004, University of Wolverhampton, UK.

Tedford, J.D., McCarthy, M.G., Seidel, R.H.A. 'Project and Team based Learning - An Integrated Approach', CDIO 2nd Annual Conference, Linkoping, Sweden, 13-14 June, 2006.

McCarthy, M.G., Tedford, J.D., Seidel, R.H.A. 'Enhancing Student Engagement through the Application of Multimedia Learning Theories to Undergraduate Design & Manufacturing Courses', CDIO 2nd Annual Conference, Linkoping, 13-14 June, 2006.

McCarthy, M.G., Effective Teaching of Complex Manufacturing Topics to Undergraduate Engineers Utilizing a Novel, Broadly Based, Interactive Virtual Company, Accepted for 2010 ASEE Annual Conference & Exposition, 20th-23rd June, 2010, Louisville, Kentucky.

Non-refereed conference proceedings

McCarthy, M., Seidel, R., Tedford, D., 'Developments in project and Multimedia Based Learning in Manufacturing Systems', Proceedings of the 13th Annual Conference of the Australasian Association for Engineering Education-Leadership in Learning, Canberra. Australia, 30 September - 2 October 2002, pp. 237-242.

McCarthy, M., Seidel, R., 'Using Multi-Media to deliver Assignments in Management Accounting for Undergraduate Engineering Students', Australasian Association of Engineering Educators, Conference, 29 September – 4 October 2003, Melbourne. Australia.

Appendix G: Notes on Course Development & Structure

7.1. Initial Course Structure

The structure and assignments of the pre-intervention manufacturing systems course was as shown in Table 7-1.

Table 7-1: Structure & Assignments of the Pre-intervention Course

Topics	Projects
<ul style="list-style-type: none"> Overview of Manufacturing Systems Structure and Elements of Manufacturing Systems Value Engineering Productivity Systems Engineering Industrial Engineering 	Manufacturing Systems Practice in New Zealand Industry
<ul style="list-style-type: none"> Product Design CAD/CAM Design for 'X' 	CAD/CAPP/CAM
<ul style="list-style-type: none"> Industrial Ergonomics Work Standards 	Ergonomics
<ul style="list-style-type: none"> Automation systems 	
1. Facilities and layout planning	
2. Review of material	

7.2. Educational Objectives

At the beginning of the research work the educational objectives of the Manufacturing Systems course were determined to be:

To acquire the ability to apply knowledge of manufacturing systems techniques engineering to the analysis, synthesis, development, implementation and maintenance of effective manufacturing processes (cf. IPENZ Competency 2, 3 and 4, see Section 7.3).

To acquire a desire to maintain currency with developments in the manufacturing systems engineering discipline (cf. IPENZ Competencies 5 and 9).

To develop further the ability to communicate competently both in written and oral modes (cf. IPENZ Competency 8).

To develop the ability to contribute productively on both internal peer and external multidisciplinary teams (cf. IPENZ Competency 7).

7.3. Requirements of the Institution of Professional Engineers New Zealand (IPENZ)

The IPENZ initial education requirements for professional engineers in for four-year engineering degrees (Institution of Professional Engineers New Zealand, 2009b) and their graduate competency profiles (Institution of Professional Engineers New Zealand, 2009a) do not mention manufacturing specifically. However, the intervention which was the focus of this research was designed to assist in the formation of the following IPENZ specified characteristics:

6. Competency 2: Knowledge of Engineering – Students understand and can apply the mathematical and engineering sciences relevant to one of the broad general engineering disciplines. Developed using presentation of multi-media course material.
7. Competency 3: Analysis and problem solving – Students are able to formulate and solve models which predict the behaviour of complex engineering systems using first principles. Developed using course tasks including manufacturing systems simulation.
8. Competency 4: Able to synthesise and demonstrate the suitability and efficacy of solutions to complex engineering problems. Developed by required output of printed solutions and computer-based models and simulation runs.
9. Competency 5: Able to recognise when further information is needed and be able to find it by identifying, evaluating and drawing conclusions from all pertinent sources of information. Developed by presenting students with indeterminate tasks and incomplete information.
10. Competency 7: Function effectively in a team by being able to work co-operatively with the capability to lead or manage a team. Developed by requiring effective teamwork as an assessed component of some tasks.
11. Competency 8: Communicate clearly by being able to comprehend and produce effective reports. Developed by presenting relatively dense written

texts to outline required tasks and requiring the submission of assessed written task completion reports

12. Competency 9: Be aware of the role of engineers and their responsibility to society by demonstrating understanding of the general responsibilities of a professional engineer. Developed by emphasising the role of the professional engineer, sometimes as independent arbitrator between operators and management in areas such as work station design, production rates, working environment and ergonomic issues.

With these competencies in mind, feedback from local manufacturing companies and advice from manufacturing group teaching colleagues the course was reformatted as shown in Table 7.2.

Table 7-2: Redesigned Structure of Post-Intervention Course

Topics	Task	Relevant Topics
Group 1. Facilities, Product and Layout Planning: facilities and layout planning; MIS; automation; data collection and networks; material handling; low-cost automation.	1. Layout new production facility.	Facilities and layout planning, MIS, automation, data collection and networks, material handling, low-cost automation.
Group 2. Work Standards and Facilities: work standards; work station design; job design; ergonomics.	2. Resolve Ergonomics Issues.	Work standards, work station design, job design, ergonomics.
Group 3. Day-to-day System Operations: capacity planning; line balancing; inventory management; aggregate planning; MRP & ERP; JIT & lean manufacturing; reliability.	3. Part A, Build model of a 'push' production line and simulate production flow. 4. Schedule production with finite resources.	Enterprise modelling, simulation and queuing theory, linear programming. Capacity planning, line balancing, inventory management, aggregate planning, MRP & ERP.
Group 4. Enterprise Modelling, Simulation and Queuing Theory: enterprise modelling; simulation and queuing theory; linear programming.	3. Part B, Model and simulate 'pull' production system.	JIT & lean manufacturing, reliability.
Group 5. CAD/CAM: CNC programming; CAD/CAPP integration.	5. Produce CNC code for part machining	CNC programming, CAD/CAM/CAPP integration.

On successful completion of the Manufacturing Systems course the educational outcomes were determined to be that students would be able to:

- Identify the key differences between product, fixed-position and process layouts.
- Apply systematic techniques to layout design.
- Link layout strategies with production planning and control techniques.
- Use current computer tools for the simulation and analysis of manufacturing systems problems.
- Recognise common causes of ergonomic problems.
- Recommend Changes to work practices/work stations to prevent ergonomic problems.
- Apply relevant work study and lean production techniques to the design of production systems.
- Understand the roles of time standards in manufacturing.
- Describe manufacturing planning & control strategies (e.g. MRP, MRP II, JIT/lean manufacturing).
- Construct a scheduling plan from a bill of materials and master schedule using finite and infinite capacity.
- Explain the role of management, supply chains and purchasing in a manufacturing company.
- Explain the concepts applying to computer-aided applications in manufacturing.
- Implement CAD/CIM concepts using computer-aided software tools.

7.4. Collaboration and Feedback

Feedback was sought from teaching and collaborating colleagues in the manufacturing systems group at the University of Auckland during the course of the development of the intervention. Much useful advice was given and a considerable amount of encouragement.

Feedback has also been received from other researchers in the field of computer-based, multimedia educational interventions in engineering. This material was generated after circulating, to leading researchers in the field, of a 'manual' containing a digest of the virtual enterprise intervention and the teaching materials that were developed.

The comments received from researchers internationally included:

I found your ideas on using business scenarios to teach students very interesting. I would be very interested in working with you in using this concept to develop additional scenarios for use with Masters Student and also as a means of skills improvement of industrial practitioners, e.g. SME owner managers.

– Dr. Con Sheehan, University of limerick.

Your work sounds really promising. Please keep in touch with the details.

- Regina Krause, Co-ordinator, UNESCO International Centre for Engineering Education(UICEE).

The research topics you have listed sound very exciting. I suggest that we seek funding/grants opportunities to do collaborative research. There must be some mutual agreements between the USA and New Zealand.

– Assoc. Prof. Can Saygin, University of Texas.

It's good to know when my earlier research has been useful and this looks to be an interesting application.

– Prof. Lydia Plowman, University of Stirling.

It appears that you have done an enormous amount of work on the course and have developed a challenging and engaging environment for your students. I fully agree that the role of narrative is central to solving problems. In our learning environments, stories play a central role in the design.

– Prof. David Jonassen, University of Missouri.