The University of Nottingham

Faculty of Engineering

A Detailed Investigation of the Applicability and Utility of Simulation and Gaming in the Teaching of Civil Engineering Students

By

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Abstract

This thesis describes research carried out into the use of computer based simulations and games in learning and with particular regard to the education of engineering students. Existing research within the scope of the subject domain was fully reviewed and documented and a list of research aims and objectives were devised. It was identified that the use of educational simulation games (a hybrid combining aspects of simulation, games design and educational content) showed potential for the teaching of organisational and project management skills.

A number of simulation games were developed during the research programme and are described. These ranged in complexity, functionality and subject domain.

The design of simulation games capable of generic modelling was investigated and proved to be a highly flexible solution enabling student business proposals to be modelled quickly and effectively to provide them with bespoke simulation games based on their plans. The simulation game was used as a coursework exercise within a teaching module for Masters level students over a three year period and results from this trial were positive and demonstrated benefits arising from the use of the simulation game.

Two complex simulation games for the teaching of construction project management were developed and extended for implementation within a teaching module. This was aimed at providing learning through the principal use of simulation games. Additional software was developed to assist in the management and monitoring of student use of the simulation games within the teaching module.

The teaching module, *Applied Construction Project Management* (ACPM), was designed to both educate the students and to inform this research work. It featured little to no traditional teaching content such as lectures and tutorials and instead relied on student centred learning and the use of simulation games as a form of Experiential or Constructivist Learning. Weekly clinic sessions and in-game communication tools were the primary mechanisms for student contact and support with the teaching staff.

Extensive quantitative and qualitative data was collected during the ACPM modules four years of operation described in this thesis. This data was collated and analysed in order to answer the research aims of the work. Results and feedback were extremely positive showing that the use of simulation games for learning can be both an engaging and effective method of learning. Issues and limitations of this approach to learning were also identified and methods for overcoming these were proposed.

Acknowledgements

There are a number of people whose assistance and support were invaluable in the production of this thesis but the principal thanks are to be addressed to my supervisor Dr Michael Mawdesley. His continual support and guidance was above and beyond the call of duty and his lecturing and teaching skills were a critical element in the delivery and execution of the practical teaching aspects of the work described.

A number of other colleagues at the University of Nottingham also deserve thanks for their help as tutors in the teaching modules delivered and for acting as teaching subjects in one of the trials described. Our international colleagues, Professor Scott and Dr Al-Jibouri, are to be thanked for their work using one of the simulation games which was an important element in the development of the simulation games and the design of the teaching experiments at the University of Nottingham.

On a personal level, I would also like to thank my parents for their unceasing belief and encouragement even when my spirits were flagging. Finally, the completion of this thesis would have not been achieved without the support and forbearance of my long term partner Sarah Roach. Over the five years, her encouragement and patience were no doubt sorely tested on a number of occasions.

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1. Introduction

1.1 Background to the work

Games and simulations in one form or another have been an integral part of the learning process as far back as has been recorded. They are an ideal solution for learning an activity when actual experience is not practical, possible, profitable or sensible. Games and play are the primary source of learning in pre-school children and there is good evidence that our love of play and its importance in our development continues throughout life. However, the increased formalisation and penetration of scholastic education throughout society during the 18th, 19th and early 20th centuries led to the widespread adopting of traditional teaching methods focussing on learning by rote and repetition. These methods were effective for the teaching of the basic levels of numeracy and literacy needed by the majority of the workforce at that time. The use of simulations and games as tools of teaching were generally discounted as professional teaching practices.

The advent of progressive educational theories (Dewey, 1938; Kolb, 1984; Papert, 1980) and the move towards a more experiential and student-centred type of learning has led to greater interest in the use of simulation and gaming in an educational context. The development and increased utilisation of e-learning is another driver for the use of computer based simulations and games in teaching.

Digital simulation and gaming provides students with an opportunity to experience an activity or process that cannot be replicated through traditional teaching approaches and is too hazardous, costly or time consuming to be performed as a teaching exercise. However, the validity of such approaches to learning is still not fully accepted and there is a need for greater assessment and research in this field.

1.2 Aims and objectives of the research

The overall research aim is to quantitatively and qualitatively evaluate the usefulness of simulation games for teaching construction management skills. A number of objectives pursuant and closely related to this principal aim were also identified and are described below:

1. Investigate the use of simulation and gaming for learning
2. Identify styles and methods of learning employed by students using simulation games in an educational context.
3. Investigate the utility and applicability of quantitative and qualitative data in evaluating student learning through simulation games.

4. Provide guidance on the design and development of simulation games for learning.
5. Investigate the balance between realism, game difficulty and learning outcomes in educational simulation games.
6. Retention, application and transferability of learning through simulation games.

1.3 Contribution to science

The work presented contributes to the body of scientific knowledge in a number of ways: It adds to the existing experimental record on student learning through the use of games and simulations and it confirms and extends existent theories on student learning processes through experiential learning. More specifically, it theorises on the effects of repeated play-throughs of simulation games on learning outcomes and it revisits the issue of distinguishing between learning to play a game and learning the subject material. Though not unique in concept these results contribute significantly to knowledge due to the extensive amount of data collected and the detailed analysis carried out over the length of the research programme. This represents an improvement over much related research within the subject domain and enables the production of more detailed models of student learning and behaviour through simulation games.

The research focuses on the teaching of construction management skills through the use of simulations and games but its findings can be broadly applied to more general application of interactive content for learning at the undergraduate level.

1.4 Research methodology

Due to both the nature of the research programme and the limitations imposed by institutional regulations in regard to the teaching of students, it was decided to adopt a combined methodology, integrating both qualitative and quantitative data. Statistical analysis of qualitative data in terms of formal and informal feedback from students is a well established methodology for evaluating the use of simulations and games and is common practice when evaluating human behaviour for educational studies as will be demonstrated in the review of this topic in chapter 3.

The scientific method requires hypotheses to be rigorously tested. Experiments or trials must be carried out under conditions where the effects of all potential experimental variables can be tightly controlled. When performing experiments with human subjects it can prove very difficult to achieve satisfactory conditions. Individual judgment or group behaviour can influence and distort the results. To assess the effectiveness of a technique or method with a group of subjects, common practice is to perform blinded or double blind trials where subjects are split into a control group and a test group where the test group uses the technique or method being assessed and the control group do not. For the purpose of this research, it would require the students being taught to be split into two groups with the test group using the simulation games and the control group being taught the material using a traditional, lecture based approach.

A blinded or double blind trial was not a possible methodology to adopt in this research for a number of reasons. Principally institutional teaching regulations prohibit the prejudicing of an individual or group of students by providing differences in learning content within a teaching module. Since it would not be possible to determine that the control and test groups were receiving identical learning outcomes it was not possible to run a teaching module in this way. A possible solution discussed was running the experiment as an optional and voluntary module but it was thought that students would be less motivated, it may be difficult to persuade a large enough sample to take such a module and most importantly it would not be a true assessment of teaching.

Logistical issues were another reason why blinded trials would have been impractical to implement (e.g. the need for additional classes or teaching staff for the separate groups and the requirement for full supervision of the use of the simulation games by the students). It would also have been difficult to select the group membership to a suitable balance of ability as the teaching modules involved were to be optional and there was no control by teaching staff over those taking the module.

For the reasons discussed it was decided that the only possible methodology for running the trials was an open trial. Care was taken to ensure that the limitations of open trials were kept in mind when assessing results from the trials.

1.4.1 Design, collection and use of quantitative data

A general lack of quantitative data in many studies on the use of simulation and games in an educational context was identified during the early stages of the project, and is discussed in chapter 3. This is seen to be a significant limitation in assessing the utility and potential for simulations and games in learning and it was therefore important to devise a methodology which incorporated quantitative measures and established a clear relationship between such measures and the objectives of the research.

Quantitative data from the initial simulations and games developed as part of the research was collected and is presented in the relevant chapters (chapter 6 and 7). The nature of those studies however limits its utility in answering the specific research questions on learning and performance but their inclusion performs another function: Specifically, in researching the design and development of simulation games for teaching. It was also from the results from these studies that the need to monitor and collect quantitative data from simulation games was verified with the findings from review of the academic literature in chapters 2 and 3.

A great deal of time and thought was spent on the designation of appropriate data and methods for capturing data on student in-game performance. The ability to monitor, and the extent of any monitoring, is heavily constrained by the nature of the learning environment, the simulation or game used and the students themselves. A teaching module was designed that was intentionally suited to full scale monitoring and forms the primary source of quantitative data in the research (chapters 8-10). Repeated runs of the simulation games used were identified as a key requirement for producing a useful quantitative dataset. This enables the effective assessment of improvement in the monitored variables and can be used to identify patterns in student behaviour that would not be easily established in a single run of the game. It was decided to maintain identical simulation settings for repeated runs of the simulation games so that the data obtained would be measured against the same baseline. Some changes to simulation settings were trialled in later research but only once the initial four runs of the games had been completed.

1.4.2 Methodology for qualitative analysis

Despite the focus on quantitative data in this study, the value of qualitative results is not overlooked. Qualitative data is a valuable tool in studies with human subjects and in the evaluation of educational practices. It is an ideal way to gain an impression of the student's view of the trial or experiment. As discussed in chapter 3, qualitative data from questionnaires, interviews and group discussions are standard methods employed for evaluating teaching practices such as those proposed in this work. Many of the case studies given in chapter 3 utilise such methods to assess their applicability. The methodology adopted in this research will draw upon these examples to acquire and assess qualitative data during the various trials and experiments that form a key part of the research. Methods used include the following:

- Questionnaires – The typical method of acquiring qualitative data in this type of study is through student questionnaires. Questionnaires for student feedback are a mandatory element of teaching modules at the University of Nottingham and this mechanism was used to collect qualitative data for the two principal trials. Standard module feedback forms were modified to include additional feedback relevant to the research aims and teaching methods being trialled.

- In-game feedback mechanisms – Feedback forms were added to the simulation games described in chapter 5 as part of this research. These were triggered on reaching specific points of progress in the games and were simplified questionnaires requiring the students to answer 8 questions. Students were also able to send messages at any time from within the two simulation games to the teaching staff. These were recorded and are referred to in the analysis of student data in chapter 8-10.
- Semi-structured interviews – A number of interviews with selected students during the primary case study were carried out. These followed a basic format of questions defined in advance, Interviews were very informal and students were not aware that they were being interviewed. This was in order to avoid any positive bias caused by the students telling the researcher what they believed they wanted to hear. The informality was also deemed necessary since there were a number of other routes available for formal feedback from the students.
- Student coursework – The coursework produced by students in relation to the two major educational trials in this study (chapter 6, chapter 8) is another indirect source of qualitative data.
- Debriefing sessions/classes – One of the primary sources of qualitative data is in the interaction between students and teaching staff during the classes held during the educational trials. It is however a highly informal data source and can only be referred to anecdotally in most instances. In the initial year of the primary trial, teaching staff recorded student queries during weekly *clinic* sessions as is described in chapter 8. For the small scale trial of one of the games in this study, debriefing sessions with the subjects were the primary source of data collection (see section 7.2)

1.4.3 Methodology for design of educational trials

The method outlined for the primary study involved a large degree of self-directed learning from the students. This was deemed necessary both by the logistical issues in terms of running the module and to exclude the effects of other methods of teaching in the results obtained. For example, the use of traditional lectures or group presentation exercises (such as those used in previous trials of one of the simulation games) would have made it difficult to establish the extent to which the simulation games are solely responsible for learning. It was also hypothesised that the students would benefit in the development of their motivational skills and ability to manage their own learning.

The educational trials involving undergraduate and postgraduate students described in this thesis utilised blended learning methods (see chapter 2) where traditional teaching practices, in this case assessment methods, are combined with more progressive methods such as the use of simulations and games and self-directed learning. The assessment of simulation or game performance was discussed at some length in planning the methodology but was rejected for a number of reasons:

- Institutional rules and the views of accreditation bodies on valid assessment methods for students would have made it very difficult, if not impossible, to include simulation or game performance as part of their graded assessment work.
- It was thought that there were significant benefits in the combination of traditional assessment with simulation and gaming. Requiring the students to produce standard reports on their simulated performance would improve their reporting and communication skills and provide them with experience in the reporting of project progress. A highly important skill for practising site engineers which students do not typically utilise in traditional teaching modules.
- It was thought that assessment of in-game performance would encourage students to place too much focus on the rules of the simulation game and may have a negative effect on their achieving the learning outcomes required.
- Since the use of the simulation games could take place outside of supervised teaching classes it would not be possible to ensure that students worked on their individual simulation games. They may work in groups or employ others to achieve high performance.
- Assessment of game performance may encourage students to attempt to circumvent the security of the games and modify data files to gain better results.

1.5 Structure of the thesis

The thesis is structured into four main elements described over eleven chapters. Chapters 2 and 3 provide the background to the research and discuss existing work in the fields of interest. Chapters 4 and 5 describe the design and development of a number of simulations and games during the research. Chapters 6-7 provide results and analysis from a number of case studies examined and undertaken during the research programme and chapters 8 to 10 focus on the principal trial undertaken. The final chapter summarises the work, drawing conclusions and examining the potential for future work and development. A more detailed description of each chapter now follows.

Chapter 2 provides a brief review of teaching and learning processes and the theories underpinning them relevant to the aims of this research. Key concepts are defined and discussed with reference to leading work in this field. Chapter 3 continues the review of existing research looking at simulation and gaming with a focus on the computer based models. Types and properties of games and simulations are described. Educational games and simulations are described in some depth and illustrated with a range of case studies. These two chapters therefore address the 1st objective outlined in section 1.2, an investigative study in the use of simulations and games in an educational context. They also provide background and baseline for many of the other objectives (e.g. the 2nd and 5th objectives through theory and example from educational theories and simulation game case studies respectively).

Chapter 4 describes the design and development of two simulation games during the research programme. One game, *BizSim*, involves the modelling of student business plans in a business management simulation. The other game, *SubCon*, is a simulation of subcontracting in the construction industry. Both aim to model a range of project or business scenarios and be reusable. Chapter 5 focuses on the extension and modification of an existing construction management simulation game, The *Muck Game*. It details the various changes made to the game to make it suitable for achieving the primary aim of this research and the relevant objectives outlined in section 1.2. The development of a new game, the *Canal Game*, a variant of the *Muck Game* is described along with a software tool necessary for this research, the *MCG Umpire*, to manage the operation of the games with students and perform tracking, monitoring and analysis of their performance. The 4th objective outlined in section 1.2 is addressed in chapters 4 and 5 due to their focus on the design, development and modification of educational simulation games. Some issues in relation to the balancing of educational content with simulation fidelity and gaming aspects are also highlighted in these chapters. This partially addresses the 5th objective shown on page 2.

In chapter 6, the teaching module employing the *BizSim* game is described. Details of the module's operation are given along with analysis of the results of this trial including feedback from students. Results from a small scale teaching trial by the author and related trials of the games used done by others are discussed in chapter 7. Trials were carried out in a variety of roles at a number of academic institutions over a number of years. Feedback from these trials was a major input to the teaching module at the University of Nottingham which forms a critical element of this work and is described in chapters 8-10.

The design of a teaching module utilising simulation games as the primary source of learning is covered in chapter 8. Brief descriptions of each year of operating the module within this research study are also included along with discussion of feedback from students. Chapter 9 looks at the data collected during the operation of the teaching module described in chapter 8. It focuses on key performance indicators of student performance and analysis of these variables for all students taking the module during its first four years of operation. Chapter 10 uses examples of individual student performance and behaviour to address many of the research questions outlined in section 1.2. It combines quantitative data, qualitative feedback and results of assessment in order to achieve this. These chapters, solely and in conjunction with, the work outlined in chapters 6 and 7, address the remaining objectives, i.e. the 2^{nd}, 3^{rd}, 5^{th} and 6^{th} objectives. They also form the primary source for the overall aim of the research, to quantitatively and qualitatively evaluate the usefulness of simulation games for teaching construction management skills.

Chapter 11 concludes the main body of the thesis summarising the main findings, drawing conclusions on the research undertaken and providing answers to the research questions posed at the start of the research. The potential for extending the work is then described with a range of examples given including changes to the simulation games, teaching and assessment methods.

1.5.1 Breakdown of the work described in this thesis

The author was responsible for the vast majority of the work described in this thesis but it is important to apportion those elements of the work done by others that are used as part of the work described here. For example, the literature and research review described in chapters 2 and 3 was done entirely by the author for the purposes of this research programme.

The development of the two games, BizSim and SubCon, described in chapter 4 was also carried out by the author, albeit with guidance and supervision from the PhD supervisor. As were, the research trials employing these two games, and described in chapter 6 and section 7.2 respectively.

The principal simulation games and software used in this research, and described in chapter 5, were developed jointly by the author and the research supervisor. The original version of the Muck game already existed though it was extensively modified and expanded as part of this work (see section 5.1.4). The Canal game and MCG Umpire software were developed in collaboration between the author and supervisor as key elements of this research project.

Chapter 7, excluding section 7.2, describes work done by others that is closely related to the aims and objectives of this research or provided inspiration for the developmental and experimental work carried out in this work.

Chapters 8-10 describe the principal experimental work carried out. This work was done entirely by the author though a number of other teaching staff were involved in supporting the teaching module. The collection, collation and analysis of student data were all performed by the author.

2. A brief review of teaching and learning methods

As stated in the introductory chapter, the work outlined in this thesis is principally concerned with the use of computer based games and simulations for teaching aspects of management, primarily construction management. In order to achieve the aims of the work it was necessary to examine and investigate relevant principles and theories from the subject domain of teaching and learning. This chapter summarises this element of the work, attempting to provide background knowledge on the underpinning research used to model and assess the work from an educational perspective. It is not an exhaustive review of the field of teaching and learning since this would require more space than available here and would be unnecessary for the purposes of this work. There are a multitude of references sources that would give a more rounded and more thorough study of this subject, many of these will be referred to throughout this chapter.

Teaching and learning is a very broad subject domain and, as with many concerned with assessing human behaviour, there are many conflicting and overlapping approaches to teaching and learning each with their advocates. Theories in teaching and learning have evolved greatly in recent times though many of the fundamental principles dating back to Socrates and Aristotle still hold true and provide useful insights into the process.

2.1 Outline and background to this chapter

Learning is the process of acquiring knowledge (*according to the Oxford English Dictionary*) and teaching is the presentation of knowledge in order to initiate learning. Teaching and learning are fundamental functions of human behaviour that start at birth and continue throughout life. They are critical to our success as a species and one of the major distinguishing features between human beings and the rest of the natural world. Kolb makes this statement more elegantly:

> *"Human beings are unique amongst all living organisms in that primary adaptive specialization lies not in some particular physical form or skill or fit in an ecological niche but rather in identification with the process of adaptation itself – in the process of learning"*
>
> *(Kolb, 1984 p1)*

Learning is the goal of teaching and the two often exist in a symbiotic relationship though learning can occur without teaching through experience alone

(Kolb.1984) but this can be slow, wasteful and even fatal in safety critical environments. Despite this, experience is a crucial element in learning (Kolb, 1984) and is especially useful in the transmission of procedural knowledge and practical skills. The combined process of teaching and learning, commonly in a formal environment, is commonly referred to as *education*.

Recent trends in the field have been to move away from traditional approaches (section 2.3.1) to make learning a more group based and collaborative endeavour with greater input from students into the whole process (section 2.3.2). Please note that the term recent is used loosely here. Many of the ideas in the progressive education field date back to Dewey (Dewey, 1938) and earlier.

Improvements in computer technology and the rapid penetration of the internet into mainstream society in the last couple of decades have created the potential for great change in teaching and learning methods through the widespread adaptation of e-learning (section 2.5). Though many still question whether such change will actually be a step forward, a dead end or even a step backwards. Ayn Rand, in particular is noted as a strong critic of progressive educational theories and referred to progressive educators as “The Comprachicos of the Mind” (Rand, 1971) for their attempts to distort the minds and thinking of students.

The process of learning will be briefly described using Kolb’s theory of experiential learning, constructivist theories of learning and Bloom’s taxonomy as the principal theories. Types of learning of interest to this research will then be described. Assessing learning is a critical element of the teaching process and forms an important element of this research work. A brief review of research in this domain is given in section 2.4. The chapter concludes with some background, theories and examples from the field of e-learning which are of interest and will guide the later research and development.

2.2 Definitions and Background

There are a number of important concepts relating to teaching and learning that are especially relevant to the research work underpinning this thesis. These will be summarised in the following sections as it is not practical to fully explain all these concepts in depth in this thesis. Appropriate references to full descriptions of these concepts are provided in the text if the reader requires a fuller understanding of the issues.

2.2.1 Pedagogy

Pedagogy is the science (or art) of teaching. It is often used to refer to teaching styles or strategies. For example, the *Socratic Method* would be a form of pedagogy as would the method of *Critical Pedagogy* proposed by Paulo Freire (Freire, 1972). Many of the methods discussed in section 2.3 are types of pedagogy.

2.2.2 Engagement

Engagement is the degree to which the learner is focused on the process of learning. It would commonly be referred to as *immersion* in a gaming context (Cheng & Cairns, 2005). Engagement with the teaching process is a fundamental requirement for learning to occur and many of the difficulties encountered by students in learning have been concluded to be caused by a lack of engagement with the teaching material (Hu & Ku, 2002). In light of this, student engagement is considered to be a very good predictor of student learning and attainment of learning outcomes (Carini et al, 2006).

However, it should be noted that engagement alone is not sufficient for learning to occur. Many activities (and in particular games) can be highly engaging yet lead to no learning whatsoever. Repenning and Lewis (Repenning & Lewis, 2005) describe the balancing between engagement and teaching content when designing games for educational purposes.

Like many of the concepts described in this section, engagement is difficult to measure and quantify. Engagement in a learning activity (or any activity) can be represented by a relative value in a continuum ranging from complete disinterest to total attention but cannot be measured with objectivity.

Kuh (Kuh, 2001), outlines some of the difficulties in assessing the degree of engagement in a teaching and learning environment. Kuh has published many papers (Kuh, 2001; Kuh, 2003; Hu & Kuh, 2002; Carini et al, 2006) reviewing the extent of student engagement in US undergraduate programmes and analysed results from the US *National Survey of Student Engagement (NSSE).* His work highlights the importance of engagement within the learning process and demonstrates methods for statistically quantifying student engagement through analysis of a large sample of student questionnaires and surveys,

2.2.3 Reflection

In this context it refers to deep or serious consideration of some subject. Reflection can occur during or after the instructional event or experience that leads to learning.

Reflection is one of the four elements of Kolb's Learning Cycle (See section 2.3.4) and the importance of reflection within the learning process cannot be understated. Reflection is often an internalised process and can therefore be difficult to quantify and to incorporate into the formalised structure of a teaching course or module. A number of methods for encouraging and increasing reflection in teaching have been proposed and evaluated as described by Brockbank & McGill (Brockbank & McGill, 2007).

Action Research and Action Learning (see section 2.3.4) are both examples of reflective processes of learning which emphasise the important of reflection within the learning process.

2.2.4 Data, Information, Knowledge and Wisdom (DIKW)

Ackoff (Ackoff, 1989) is regarded as developing the DIKW hierarchy linking data, information, knowledge and wisdom though there are actually a number of earlier references to similar definitions. Ackoff's work is commonly cited as a principal source in this area and is a sufficient reference for the purposes of this brief discussion.

This is sometimes known as the Knowledge Pyramid (as shown in figure 2.1) and is an important definition in the fields of knowledge management and information systems. It also has relevance here since the transmission of knowledge is often regarded as the primary aim of learning and it is necessary to define the exact nature of knowledge and how it differs from data and information. The definition of wisdom is not directly relevant to this research but will be given for the purposes of clarity.

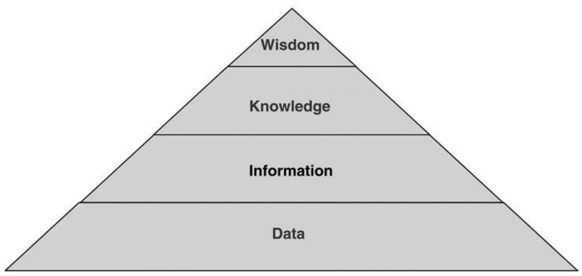


Figure 2.1 : The Knowledge Pyramid taken from Rowley (Rowley, 2007)

2.2.4.1 Data

Data is defined as a set of symbols that exist in some form that may or may not be usable. Data has no meaning and is the raw state described in the DIKW model. The contents of an Excel spreadsheet without headings would be a typical example of data.

Fricke (Fricke, 2009) provides a more detailed explanation of the definition and role of data in the DIKW model including discussion on the “truth” of data and its relationship to evidence. It is not relevant to this research to explore this topic any further here.

2.2.4.2 Information

Information is data with meaning or semantics applied to it. It differs from raw data in that it can be used to answer simple questions of who, where, what and how. Referring back to the example given for data, information could be described as the content of an Excel spreadsheet with headings applied. Ackoff (Ackoff, 1989), Rowley (Rowley, 2007) and Fricke (Fricke, 2009) all provide detailed descriptions of information and the role in plays in the knowledge pyramid and the reader is directed to one of these sources for further information.

In the context of learning, information is provided to students during the learning process and the learning process aims to transform this information into knowledge which can then be retained and applied by the student to indicate that learning has been successful.

2.2.4.3 Knowledge

Education is commonly regarded as the imparting of knowledge from a teacher to a student and knowledge is often regarded as the principal output of education. Rowley defines knowledge as follows:

> *Knowledge is know-how, and is what makes possible the transformation of information into instructions. Knowledge can be obtained either by transmission from another who has it, by instruction, or by extracting it from experience*

[Rowley, 2007 p166]

Referring back to the spreadsheet analogy described in the previous sections, knowledge would include an understanding of any formulae in the spreadsheet and how the contents of the spreadsheet can be adapted or extended for other uses or views of the data.

The acquiring of knowledge, though fundamental to learning, is only one element of the learning process. Retention is the degree to which information and knowledge is recalled after some interval from its acquisition. This interval could include immediate recall after transfer of knowledge but most commonly implies some delay from knowledge acquisition to recall. The length of retention and degree of retention are obviously critical measures in assessing the extent and value of any learning occurring.

Once knowledge has been acquired and retained the next stage in the learning process is in the application of that knowledge to solve problems. Being able to apply relevant knowledge in a new context demonstrates understanding of the knowledge and is an indicator that real learning has occurred. Knowledge that cannot be applied is of poor quality and may be no better than information.

2.2.4.4 Wisdom

Wisdom is at the pinnacle of the DIKW hierarchy described by Ackoff. It is often considered to be the most inadequately defined element of the model and a number of authors have attempted to clarify its definition and role in the overall model including those referred to here (Rowley, 2007; Fricke, 2009). Rowley's definition for Wisdom is as follows:

> *"Wisdom is the ability to increase effectiveness. Wisdom adds value, which requires the mental function that we call judgment. The ethical and aesthetic values that this implies are inherent to the actor and are unique and personal."*

[Rowley, 2007 p166]

Wisdom is of some interest to this work in its relationship to judgment. Decision making in construction management processes often call for the application of engineering judgment and the term is referred to in the learning outcomes for the teaching module that forms a major component of this research (and is discussed in chapter 8-10).

Wisdom goes beyond the ability to answer *How* questions (that would be the domain of knowledge) and extends to the *Why* questions. It requires a deeper level of understanding. Wisdom is an extension of knowledge and is generally gained through extensive experience (Ackoff, 1989). It is not easily imparted through education alone.

The more ephemeral nature of wisdom makes it difficult to assess the extent to which a person has wisdom in relation to a subject domain or task and no further mention of it will be needed within the scope of this thesis.

2.2.5 Learning Outcomes

Learning outcomes can be broadly categorised as the aims and objectives of a learning exercise from the student's point of view. These can fall into a number of categories and classifications including the more abstract (ability to think critically) to the concrete (understanding of project planning using activity networks).

Jonasson (Jonasson, 1997) discusses the design of learning outcomes for problem solving and describes how learning outcomes should be devised to suit the nature of the problem being presented as a learning experience.

2.2.6 Learning Styles

Research has lead to the identification of specific styles of learning that are adopted to greater or lesser degrees during the learning process. Kolb (Kolb, 1984) describes many of the styles are typically found during learning. Styles are determined both by the nature of the learning experience and the cognitive preferences of the learner.

The learning style adopted by a specific learner is not fixed and an individual may adopt a number of styles of learning in any learning process. It seems evident from the literature (e.g. Kolb, 1984), that preferences in learning style can impact on the extent of learning both positively and adversely.

Issues and effects in learning styles will be explored later in this chapter under the description of Kolb's Experiential Learning process and the description of the *learning styles inventory* (section 2.3.6)

2.2.7 Learner modelling

Extending from the concept of learning styles is the modelling of learners. Learner modelling includes a variety of methods and techniques for assessing an individual's learning styles and methods.

It can refer to a simple record of all a learner's activity and responses during a learning exercise. These types of learner models are commonly employed in e-learning and in particular, Intelligent Tutoring Systems (section 2.5.1). The Learning Federation roadmap (Howell, 2003) on learning modelling discusses this type of learner modelling in some depth with discussion of the salient points. Research in the use of e-learning with students will typically require some sort of learner model (except for the most rudimentary of e-learning exercises) in order for analysis of the use of the learning system to be performed.

Alternatively, learner modelling could refer to the use of some technique, commonly psychometric type testing such as the Myers-Briggs Type Indicator (Briggs Myers et al, 1998) or the Learning Styles Inventory model described by Kolb (Kolb, 1984). The results of the testing can then be used to classify a learner's approach to learning and to devise the most appropriate learning experience to suit their particular predilections.

2.3 Types of Learning / Learning mechanisms

Numerous theories of learning and mechanisms by which learning occurs exist in the published literature. These come from the fields of education, psychology and cognitive science (amongst others). This research aims to draw upon this work somewhat but is not intended as a full review of educational theories as this falls well outside the scope of this work.

In this section, a number of key theories and approaches to defining the process of learning are briefly described. The broad stereotypes of traditional and progressive educational methods are described to provide some context and background. However, the focus is exclusively on those aspects that are fundamental or directly related to the aims of this work. In particular the classification of learning commonly referred to as Bloom's Taxonomy, the theory of Experiential Learning proposed by David Kolb, the theories of Constructivist Learning pioneered by Jean Piaget and the constructionist approach to learning championed by Seymour Papert are detailed in some depth.

2.3.1 Traditional Teaching (Tell-Test Approach)

Traditional teaching is probably a much overused term in publications. It is generally is used to refer to a teaching style where material is presented to a group of students in a classroom or lecture type setting. There is little interaction between teacher and students with the student's role in the teaching process being an essentially passive one. The interaction that exists is purely in the presenting and receiving of information or knowledge with little or no discussion of the material between teacher and students. In a traditional teaching exercise, the teacher manages the teaching and learning process, defining the structure and content of curriculum. Assessment methods also follow a traditional approach where the student's success at learning the material is achieved through examination and coursework based approaches where examination is likely to be the dominant method of assessment.

Learning by Rote, a repetitive approach still widely used in teaching many types of knowledge both in the UK and internationally, is a typical example of the traditional approach to teaching being discussed in this section. Learning by rote can be very effective in the teaching of certain types of declarative knowledge such as basic arithmetic and literacy but has many critics.

Instructionism, or instructivism, is another term found in the literature referring to the more teacher-focussed and traditional methods of teaching being described here. For example, Papert (Papert, 1991) uses the term to contrast with his theories on constructionist learning.

Many academics criticise this type of stereotyping of teaching methods as being crude and unfair depictions of classroom based approaches which actually exist within a continuum of styles. These can include the more passive method depicted to active and interactive learning sessions where teacher and students are highly engaged and partake in free and open debate of the teaching material. In fact, Dewey makes this distinction and warns of the lazy stereotyping of traditional teaching approaches in his seminal work *Experience and Education* published back in 1938 (Dewey, 1938),

Prensky (Prensky, 2001) uses the term *tell-test* as a shorthand or reference for this type of teaching method which seems appropriate. This is the term that will be commonly adopted in this thesis when contrasting the various approaches reviewed and adopted against a standard lecture based approach to teaching undergraduates.

2.3.2 Progressive Learning/Education

Progressive education is the antithesis of traditional teaching as described in the previous section. The idea of progressive education and learning has been around since the 19th century but was popularised in the early to mid 20th century. John Dewey is probably the most famous proponent of progress educational methods and his 1938 book, *Experience and Education* (Dewey, 1938), is both a rallying call for the introduction of progressive education and an attempt to pacify traditionalists by clearly defining the aims and objectives of progressive education. Dewey further clarified the ideas of progressive education in later works in this field (Dewey, 1994; Dewey, 1959).

Progressive education is an inspiration for many of the learning methods described in section 2.3 and shares many methods in common. The progressive school of education emphasises:

- Learning by doing
- Group based learning
- Problem solving and critical analysis
- Collaborative/Cooperative Learning

- Lifelong learning
- Learning outside the context of the classroom
- Integrated and flexible curriculum
- Opposition to standardised testing

Progressive learning became more widely accepted during the 20th century and elements of it are now common practice in education. It is however, a contentious philosophy of learning and there still exists many who are diametrically opposed to the tenets of progressive education. A common critique of progressive education is that its lack of rigid formal definition makes it difficult to critically assess the results and leads to wide divergence in student performance (Evers, 1998).

Progressive education is a broad term that includes a range of teaching and learning methods and styles and would include the work outlined in this thesis.

2.3.3 Bloom's Taxonomy

Bloom's taxonomy of educational objectives (Bloom, 1956) is one of the most widely cited educational references (Orey, 2001). It was created by a group of educators led by Benjamin Bloom and published as a handbook in 1956. The taxonomy provides a method for classifying and categorising learning in three specific domains. These are:

- Cognitive – The domain of knowledge categorised into six specific levels
- Affective – related to attitudes and emotional aspects of learning. Categorised into five separate levels
- Psycho-motor – Concerned with the skill based domain of practical activities and split into six separate levels.

For the purpose of this research, only the cognitive domain is of relevance. The six levels of the cognitive domain work as a sequential hierarchy structured in a pyramidal format where a learner progresses up the hierarchy as learning occurs. For example, a student at the stage of *analysis* has already achieved the *knowledge*, *comprehension* and *application* stages. This pyramidal hierarchy from the original version of the taxonomy is shown in figure 2.2.

In order to further clarify the use of Bloom's taxonomy, each stage is often described by a range of verbs that represent the actions and activities that would be carried out during that stage of learning. Examples of these verbs are shown in figure 2.3 which is often referred to as Bloom's Wheel.

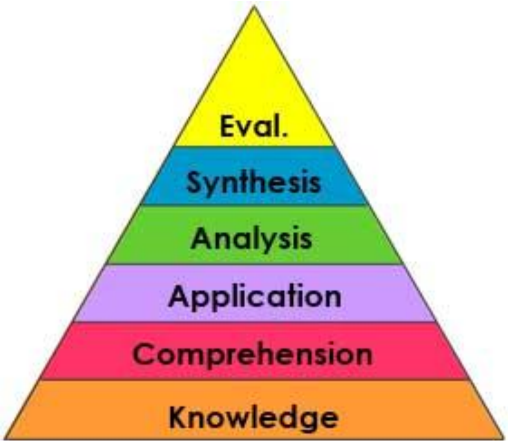


Figure 2.2: Categories within the cognitive domain of Bloom's Taxonomy (original version)

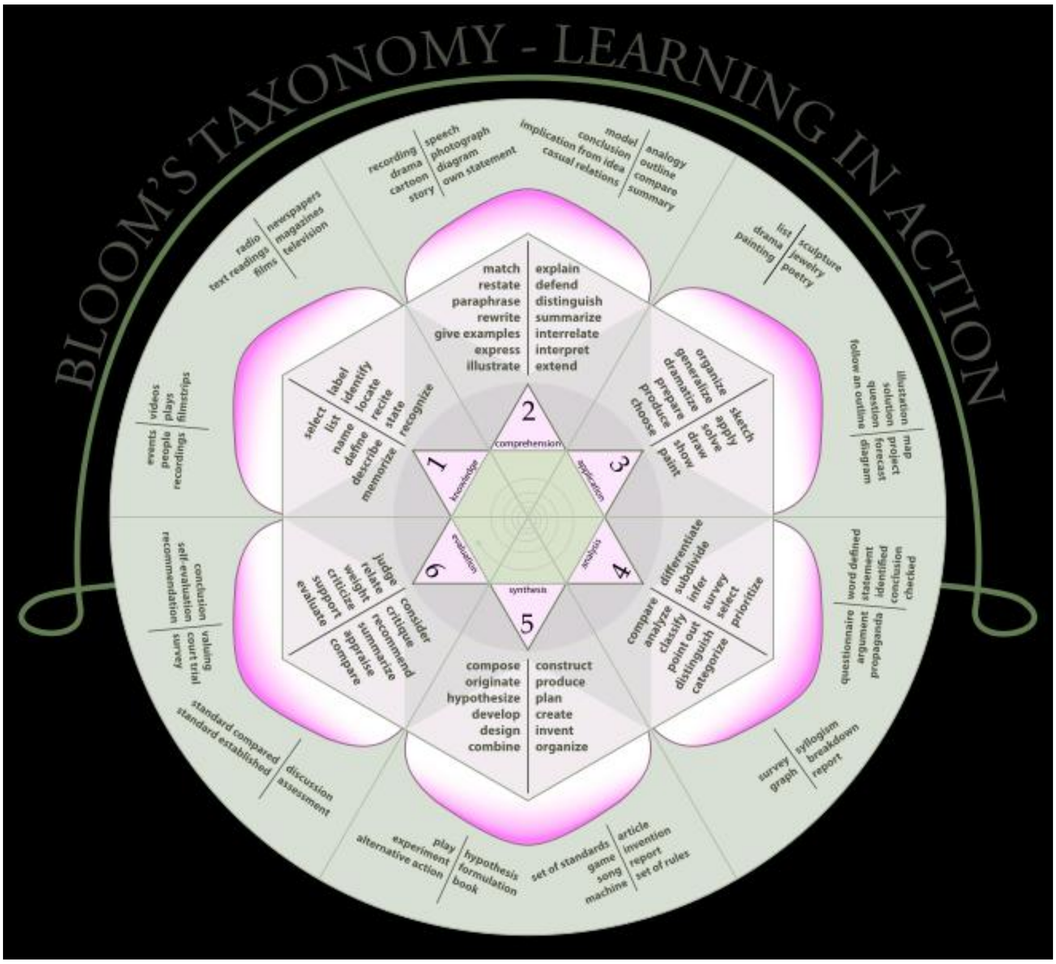


Figure 2.3 : Bloom's Wheel showing categories, matching verbs and assessment types - original version (taken with permission from wikicommons)

Anderson (Anderson & Krathwohl, 2001) provides a revised version of the taxonomy taking into account many of the criticisms made since its creation and completing aspects of the taxonomy that were incomplete. Figure 2.4 shows the categories in the cognitive domain from the revised version. The main change in the cognitive domain being converting the original noun based category descriptions to verbs and the exchange of *synthesis* and *knowledge* (old version) for *create* and *remembering* (revised version). The categories are often shown in a pyramid type hierarchy with create, evaluate and analyse at the top of the pyramid respectively. The structure shown in figure 2.4 represents a view of the cognitive domain where the topmost categories are given equal weighting which reflects the opinion of many educators.

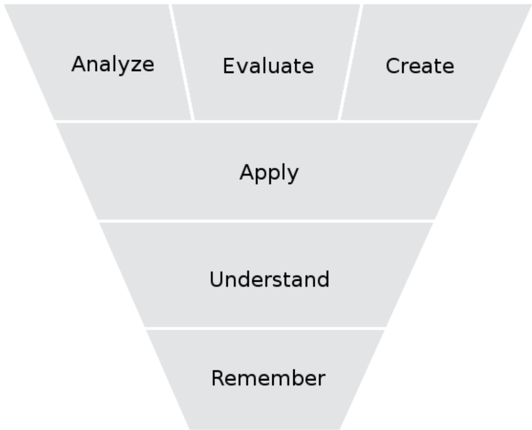


Figure 2.4 : Categories in the cognitive domain of Bloom's Taxonomy (revised version)

2.3.4 Action Research and Action Learning

Action Research (Lewin, 1951) is a method of learning whereby groups interact to reflect on some experience or activity. These groups are referred to as *T-Groups* and work in a cyclic format of action and reflection. The method is commonly used in organisational development processes as well as within the field of education. Often a facilitator from outside the T-Group is employed to direct the experience (in an educational context this role would be taken by the tutor). Action research can employ a number of tools including simulation, case studies, games or role—playing exercises in order to create a dialogue and discussion between T-group members and generate learning. Kolb (Kolb, 1984) provides a detailed explanation of Lewin's work and its relationship to his own theory of Experiential Learning.

Action Learning is closely related to Action Research and was developed by Prof. R Revans. It again uses the ideas of small groups, referred to as *action learning sets*, and uses discussion and dialogue through example or simulated exercises to produce learning. It is also used for both educational purposes and organisational development. Revan (Revan, 1980) describes the process in more depth than can be detailed here and a more recent and practically focussed review of the method is provided by Weinstein (Weinstein, 1998).

Dick (Dick, 1997) also provides a brief overview of these related learning methods and their relationship to some of the other theories and methods outlined in this chapter).

2.3.5 Constructivist Learning and Constructionism

Though similar sounding these two related epistemologies do differ and both have relevance to this work and will be described in this section. Essentially both theories are concerned with the construction of knowledge by the student during the learning process and are related to experiential learning. They are both highly relevant to this research as they are closely related to the use of simulation and gaming approaches to learning.

2.3.5.1 Constructivist Learning

This theory of learning was developed by the great Swiss Psychologist, Jean Piaget. His extensive work studying the development of children led him to conclude that play was an essential element in learning. Constructivist theories of learning have become widely accepted and underpin many theories of learning (including Kolb's theory of Experiential Learning described in section 2.3.6) though there are a number of criticisms of constructivist theories of learning as outlined and discussed by Liu & Matthews (Liu & Matthews, 2005). Some general principles of the constructivist approach to learning are as follows:

- Learning is an active process – It requires more than just the passive acceptance of knowledge presented by a teacher. The student must be actively involved in the process.
- The process of learning itself is part of the learning process – The more a student learns about a subject domain, the more they are able to construct a method for integrating the knowledge into a coherent understanding.
- Constructing meaning from learning requires reflection – This is a mental process and though physical actions can assist in learning they are not sufficient for learning to occur. Students must internally reflect on the learning experience for meaning and understanding to develop.
- Learning is a social activity – debate and discussion with peers and teachers are an essential part of the learning process

- Context is key to learning – The relevance of knowledge to an individual is crucial for successful learning. Students gain more from teaching if the content has relevance to their life or work.
- Learning builds upon existing knowledge - The more we know, the more we can learn. Teaching must be based on the current knowledge state of the learner if it to be truly successful.
- Learning is not instantaneous - For significant learning we need to revisit ideas, ponder them try them out, play with them and use them.
- Engagement is a key component in learning. Not only is it the case that motivation helps learning, it is essential for learning.

Many of these principles are similar or extensions of those outlined as features of progressive education in section 2.3.2. This is not surprising since the constructivist theory of learning is at the heart of progressive educational attitudes. Duffy and Jonasson (Duffy & Jonasson, 1992) discuss the use of constructivism and its links to the technology of learning in more depth than is possible here.

2.3.5.2 Constructionist theory of learning

The famous educational theorist and practitioner Seymour Papert is the driving force and originator behind constructionism and the contructionist theory of learning, it is based on his work in the 1970s and 1980s with the use of Lego and logo and is detailed in his book, *MindStorms: Children, Computers and Powerful Ideas* (Papert, 1980). It builds upon Piaget's constructivist approach to learning and is closely related to Kolb's theory of Experiential Learning.

Papert's work on Constructionism focuses heavily on the use of IT in teaching and he is a strong proponent and defender of the use of e-learning (see section 2.5). The Constructionist approach to learning focuses on learning through the creation of a physical or abstract system by the student as the principal element of the learning process. It is often referred to as *Learning by Making* (Papert, 1991).

Constructionism shares much in common with Schank's work on learning through Goal-Based Scenarios (Schank et al, 1993) and both are highly relevant to the use of computer based simulations and games in learning.

2.3.6 Experiential Learning

Experiential Learning is a theory proposed by David Kolb in his 1984 book *Experiential Learning: Experience as The Source of Learning and Development* (Kolb, 1984). It draws heavily on the ideas of John Dewey, Jean Piaget and Kurt Lewin already described in this chapter. It is learning by reflection on doing and focuses on the individual with no necessity for a teacher. It shares much in common with the theories already described in this chapter (except for traditional education).

Experiential learning can be thought of as being in two types; where an individual learns through their direct life experience such as through on-the-job training or whereby a student acquires knowledge and skills in a suitable environment by experiencing the task or process to be learnt (or some facsimile of it such as through simulation). The latter is the type of experiential learning of relevance to this work and Kolb describes how experiential learning can be carried out in an educational institution in chapter 7 of his book (Kolb, 1984). The use of simulated learning environments is highlighted as a potential mechanism for the delivery of experiential learning outside of actual experience itself.

It is not possible to discuss the theory in any depth within this thesis but there are a multitude of references to experiential learning including Kolb's original book.

2.3.6.1 Kolb's Learning Cycle (or Circle)

A key concept in the theory of experiential learning is Kolb's Learning Cycle (sometimes referred to as Kolb's Learning Circle). This is derived from the learning models proposed by Dewey, Lewin and Piaget and is shown in figure 2.5. It closely resembles the model outlined by Lewin.

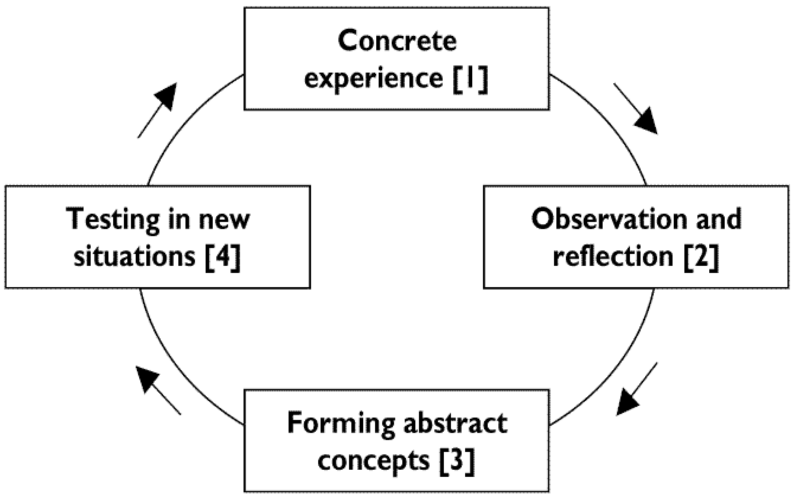


Figure 2.5 : Kolb's Learning Cycle from (Kolb, 1984)

These represent the steps in the learning process and are shown as a cyclic pattern, though in reality all the steps could be occurring at once. The cycle starts with *Concrete Experience* where the learner experiences some activity (through their direct interaction or observation of it). The learner then reflects upon this experience through observation and develops understanding. In third step, the learner uses this understanding to develop a conceptual theory as to how the experienced activity or item would operate. They then test their abstract theory in a variety of situations in the final step. The cycle then repeats itself until full learning has occurred and no more can be learnt about the experience.

The four elements of the learning cycle are generally abbreviated as follows:

- CE – Concrete Experience
- RO – Reflective Observation
- AC – Abstract Conceptualisation
- AE – Active Experimentation

Each element is required for learning to various degrees depending on the nature of the learning environment, the learner's style and the nature of the material being learnt.

2.3.6.2 Learning Styles Inventory (LSI)

Central to Kolb's theory of experiential learning is the individuality of the learner. Kolb proposes that learner's adopt a variety of styles during the learning process which are dependent on a number of factors. A learner's style is not a fixed psychological type but will adapt in response to environmental and experiential conditions though each individual will have a tendency for specific learning styles and strategies in similar conditions.

The LSI is a method used to assess an individual's orientation towards learning based the four elements of the learning cycles (CE, RO, AC, and AE). The four learning styles identified by Kolb are shown in table 2.1.

The LSI is a self reporting test where participants answer a series of questions that focus on the four elements of the learning cycle and seek to assess their relative emphasis on each of these four learning modes. It produces a series of scores mapping the participant's relative predilection to these modes. Kolb describes how the results of LSI style testing can be used to create appropriate teaching strategies for an individual that are tuned to their individual learning preferences. He also provides results from testing a range of student types to demonstrate particular aptitudes and learning styles within academic and professional disciplines.

Felder & Silverman (Felder & Silverman, 1988) describe the learning styles and methods as they apply specifically to engineering students and relate how teaching methods can be made more suitable for these types of student. This work is of great relevance to this research due to its focus of engineering education.

Learning style	Learning characteristic	Description
Converger	AC+AE	· strong in practical application of ideas · can focus on hypo-deductive reasoning on specific problems · unemotional · has narrow interests
Diverger	CE+RO	· strong in imaginative ability · good at generating ideas and seeing things from different perspectives · interested in people · broad cultural interests
Assimilator	AC+RO	· strong ability to create theoretical models excels in inductive reasoning · concerned with abstract concepts rather than people
Accommodator	CE+AE	· greatest strength is doing things · more of a risk taker · performs well when required to react to immediate circumstances · solves problems intuitively

Table 2.1: Kolb and Fry on learning styles (Tennant, 1996)

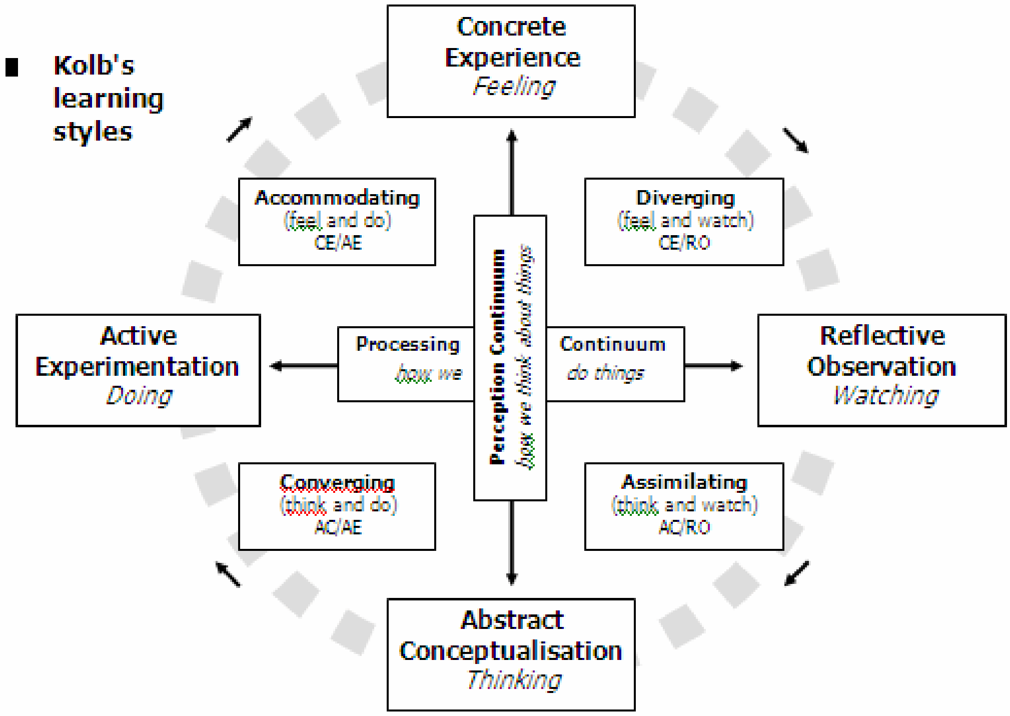


Figure 2.6 : Kolb's Learning Cycle and Learning Styles (from © concept David Kolb, adaptation and design Alan Chapman 2005-06, based on Kolb's learning styles, 1984)

A full diagram showing the learning cycle with the inclusion of the learning styles discussed in this section is shown in figure 2.6. It also shows that a continuum exists between the opposing modes of the learning cycle. Learners can be placed at some relative point in this continuum as determined through the results of LSI style testing.

2.3.6.3 Limitations and Criticism of Experiential Learning

Whilst the theory of experiential learning is now widely accepted and proven to provide educational benefits in a variety of subject domains, working environments and academic disciplines it is not without its detractors and its limitations as noted by a range of researchers (e.g. Anderson, 1988; Tennant, 1997)

- The process of reflection is not fully explained or explored
- The four learning modes defined do not apply for all potential situations
- It does not take account of cultural differences in terms of the learning process
- The sequential model of the learning cycle does not necessarily represent the actual thinking process – Kolb himself, states the cycle may actually occur all at once
- There is not enough empirical evidence to support the theory

It is clear that care must therefore be taken when applying Kolb's theories. However, as Tennant points out:

> *'the model provides an excellent framework for planning teaching and learning activities and it can be usefully employed as a guide for understanding learning difficulties, vocational counselling, academic advising and so on'.*

(Tennant, 1997 p92)

2.3.7 Miscellaneous learning methods relevant to this work

In this section a brief description of other learning methods that bear some relevance to this research are provided.

2.3.7.1 Problem Based Learning (PBL)

Similar to Case Based Learning (CBL) or learning by example, PBL is a student-centred learning method where small groups of students are given open ended problems to solve and then reflect upon the experience. Problems used are usually closely based on real world problems and may often have no one solution and often involve a compromise between multiple objectives

The learning process is facilitated by a teacher though their role in to guide the learning process and not to provide additional information on the problem (beyond that initially provided) or answers to student questions.

2.3.7.2 Blended Learning

Blended learning is a term used to describe a hybrid learning method that combines aspects from two or more learning methods. The combination of methods will be designed to suit the needs of the students and the learning outcomes.

A typical blend would be in the combination of some progressive and traditional approaches to learning. An example of this would be the use of traditional assessment methods within a progressive learning experience, i.e. students undertake some sort of constructivist learning but are then tasked with completing a standard examination or coursework report based on their experiences.

2.3.7.3 Situated Learning

Situated Learning is a form where learning takes place in the actual environment in which the experience will be carried out, e.g. on the job training. It involves a *community of practice* which is similar to a T-group (Action research) though more vocationally focussed.

It might typically involve some form of role playing exercise where the learners play out the real world experience in various roles and reflect upon their performance. It is generally used in adult learning and with a more vocational than pedagogic focus.

2.3.7.4 Discovery Learning

Discovery learning is a method of progressive learning popularised by Jerome Bruner (Bruner, 1961) which draws on the work of Dewey, Papert and Piaget. It is an inquiry based instruction method where students are tasked with tasks which they solve based on their own experience, prior knowledge and through interaction and experimentation with the learning environment. Bruner felt that students would best remember and understand concepts that were discovered through their own individual actions.

It shares much in common with Constructionism and Experiential Learning though it has many critics as to it efficacy as a teaching method due to it lacks of formal structure and guidance. Extensions to the method exist that attempt to reduce these limitations, e.g. *guided discovery learning*

2.4 *Assessment methods employed in teaching and learning*

One of the primary difficulties in educational research is in the objective assessment of learning. This is a critical area since without accurate and effective assessment it is impossible to ascertain the relative value of a teaching method and to ensure that students are receiving appropriate teaching support. Howell (Howell, 2003) discusses many of these issues and also highlights that the wide variety of learning methods available also exacerbate this problem.

One of the critical aims of assessment is to provide feedback on the learning process to both the teacher and the student. This feedback should enable the student to focus their attention of their weaknesses and provide the teacher with guidance on where to focus additional teaching support and in the planning of further teaching content to achieve the learning outcomes.

It is not possible to investigate this topic in any depth within this chapter but key points and types of assessment will be briefly described that are of relevance to this work. Some of the key issues in assessment of learning are:

- How do we assess learning?
- Who performs the assessment?
- Subjective versus objective assessment
- Design of exams, coursework and other testing methods
- Improvement versus attainment
- Relative versus absolute performance
- Rates of learning and their impact on assessment
- Cross-disciplinary issues in assessment
- What objective measures (if any) can be utilized in assessment?
- How can subjective assessment be normalised to ensure consistency of assessment?

There are a wide range of answers to the various issues mentioned and it is not possible to review them all here but the list provided acts to illustrate the obstacles that must be considered when evaluating student learning. The specific assessment topics relevant to this work will now be discussed in greater depth.

2.4.1 Traditional approaches to assessment

Traditionally assessment is carried out by the teacher or tutor. It can be subjective or objective depending on the nature of the material being assessed. Typically, science and mathematical based material can be effectively assessed objectively and arts based teaching is subjectively assessed (though there are many exceptions to this rule).

Typical traditional methods for assessment include question based tests such as formal examinations or classroom quizzes and standard coursework exercises assessed by reports or essays. These methods have been in existence since the inception of formal scholastic education and are well proven and documented methods of assessment. They are well understood by students and are accepted by the wider society.

However, traditional assessment methods have many critics and limitations. A testing based approach to assessment is not suited to all types of learner especially in a formal examination type format. It is biased towards those students who are effective at memorisation and are able to recite model answers. Though these skills have some relationship to the attainment of learning outcomes they do not necessarily demonstrate full understanding and the ability to form theories and apply them to real world problems. Coursework based reporting and essay writing is also prone to plagiarism due to its unsupervised creation and cannot be confirmed as being the work of the learner.

Another significant problem with traditional approaches to assessment is that they are extremely time consuming and/or labour intensive activities. Most members of the teaching professions spend a significant portion of their time assessing student material.

2.4.2 Peer and Self-assessment

Peer and self-assessment methods have always being a part of the learning process to some extent but its formal inclusion within the teaching process is a relatively modern development. It can provide a number of benefits but has some significant obstacles to its use.

It provides the students with a greater appreciation of the assessment process and can also increase their understanding of the learning material. It encourages reflection on learning and increases the degree of group based discussion. It also reduces the amount of assessment to be carried out by the teacher and can help the students understand the reasons for their individual assessment results in greater clarity.

However, there are significant overheads and difficulties in employing peer based and self assessment methods. Students must be provided with information and knowledge on assessment procedures and must agree to a set of assessment rules and regulations that they can all agree to. There are risks that negative assessments may introduce tension and conflict between students in peer assessment exercise and that personal relationships may bias their judgment. In self assessment exercise some students may not be willing to be sufficiently objective regarding their own work. Most critically, if the assessment is summative (see section 2.4.3) then there is likely to be institutional or regulatory opposition to its introduction. For this reason much of the peer and self assessment exercises documented are formative assessments only.

Hattum-Janssen & Pimenta (Hattum-Janssen & Pimenta, 2006) provide an excellent case study on the challenges, benefits and limitations of employing peer and group based assessment within a teaching module. Kosel (Kosel, 2006) also provides details of peer, self and group assessment methods in PBL. The reader is urged to consult these references for an in depth discussion of this topic.

2.4.3 Formative and Summative assessment

Formative assessment is feedback on student or learner progression that does not produce an audited grading going towards a qualification. An example of this would be a random classroom test or quiz that is aimed at providing students with some feedback on their learning but does not go towards their final grade. In contrast, summative assessment is formally graded assessment material that is used in the production of a mark or grade of student achievement.

An example of the use of formative assessment in the learning process can be found in the work of Nicol et al (Nicol et al, 2006). Both these types of assessment have their role in the learning process though the nature of traditional teaching tends to focus on summative assessment methods.

2.5 E-learning

E-Learning (sometimes referred to as Electronic Learning or eLearning) is an ill-defined term that has been used to refer to all forms of teaching that employ IT resources or just those that employ web based distance learning methods (and many definitions in between those two extremes). In this thesis it is used as an encompassing term for all learning that employs IT equipment and software tools to assist in the learning process.

This section is provided to illustrate the various forms of E-Learning as they represent alternative teaching methods. E-Learning through computer based simulation and gaming is the primary focus of this work and is described in depth in chapter 3. This section will instead briefly describe other elements of E-Learning such as Virtual Learning Environments (VLE), Computer Assisted Assessment (CAA) and

Intelligent Tutoring Systems (ITS). It is not intended as a detailed study into the field of E-Learning as this is not warranted in this work.

2.5.1 Growth in E-Learning in Higher Education

The penetration of e-learning within higher education has increased dramatically within the last two decades. This has to some degree coincided with the growth of the world-wide web and its implications for learning (e.g. *Google generation has no need for rote learning*, Times Educational Supplement, December 2nd 2008)

Computing facilities are now widely available to all students at UK universities and it is no longer uncommon for students to possess their own laptop PCs. Increases in computing power and network bandwidth combined with the increased availability of educational software licensing agreements and the growth of the free/shareware movement mean that powerful computer applications are now easily available to students. Higher education institutions now employ IT based methods as the default mechanism for communicating with their students and typically provide teaching materials though this medium (through intranets and applications such as WebCT)

This has all led to a massive increase in the use of computing resources by students in higher education and has been a paradigm shift in the nature of the higher educational learning.

2.5.2 CBL/CAI /CAL – Computer Based Learning, Computer Aided Instruction and Computer Assisted Learning

These methods of learning are now commonly employed in industrial training and undergraduate education. They cover a wide range of potential methods and CBL and CAI are terms that are interchangeable with E-Learning in many definitions. CBL commonly refers to learning through specialist programs and applications designed for learning which could include many of those described in the following sections. CAI often refers to the use of a computer as a self-contained teaching tool.

CAL is another term that has been superseded in many references by E-Learning. The two terms are completely interchangeable though some prefer CAL over E-Learning.

2.5.2.1 Web Based Learning (WBL)

WBL generally refers to distance learning through the use of interactive websites though it could also be a classroom based exercise where a teacher supervises students using web based materials. WBL generally refers to the use of specially designed educational websites rather than general browsing though this could form part of a structured exercise (e.g. asking students to track down information from a range of internet based resources to examine the accuracy and reliability of internet based research).

2.5.3 ITS – Intelligent Tutoring Systems

ITS are a form of E-Learning used to teach students in the absence of a teacher (though teaching staff may be present in a supervisory role to ensure that the learning exercise is carried out successfully). The ITS takes the role of the tutor and presents teaching and assessment material to the student according to their interaction with the ITS.

These types of system utilise Artificial Intelligence (AI) techniques in order to simulate the tutor’s role and have much in common with Expert Systems.

2.5.4 Virtual Learning Environments (VLE)

VLEs can include a range of potential systems that can provide learning and support for learning processes through technology. Examples of items contained within VLEs in a higher educational context include:

- Digital resources – The simplest form of VLE. Non-interactive collections of standard teaching materials such as lecture notes. These reduce the need for the wasteful printing of teaching materials by teaching staff. They also provide the students with instant access to notes and lecture materials and the ability to quickly search for the information they require
- Communication tools – Could range from email and instant messaging to online forums and bulletin boards. Enables student to communicate with teaching staff outside of formal classes and provides methods for communication between student peer groups and work groups. Also allows for discussion with relevant parties outside of the teaching class which could include industrial contacts or other academics.
- Interactive and assessment based content - Self Tests and exam materials. Links to interactive or external resources. Video lectures. Podcasts.
- Collaborative Tools – systems or applications designed for computer based support of working groups of students. Could include commercial software or bespoke tools created by combining many of the previously described elements with work applications.
- Online Courses – These could include a whole teaching module or course specifically designed to be used through a computer system. MIT’s OpenCourseWare programme would be an example of this type of VLE content.

- 3D Multiuser environments – These allow the user to interact through some 3D avatar in a 3D graphical environment to access learning materials and communicate with other avatars representing other students or teaching staff. They also have the potential to produce a more interactive and immersive model for learning. *Second Life* (published by Linden Labs) would be the most obvious example of this type of VLE and has received much attention from educators in recent years.

Advantages of VLE's include:

- Supports flexible learning and/or distance learning
- May reduce feelings of isolation for distance learners, part-time students
- Can encourage less confident students
- Can improve communications between lecturer and students
- Helps students prepare for/review topics
- Usually easy to set-up and administer

2.5.5 Assessment of E-Learning

E-Learning can be assessed through a variety of methods depending on the nature of the type of E-Learning. It can utilise the various forms of assessment described briefly in section 2.4. Where E-Learning is assessed though traditional approaches (reports and tests) it is an example of blended learning (section 2.3.7.2).

2.5.5.1 Computer Aided Assessment

This refers to a range of computer based exercises that are used to assess the user's ability within a subject domain. Typically they consist of multiple choice type tests though more complex testing regimes are possible (though it is obviously difficult for a computer based system to assess the answers to essay type questions)

Computer Aided Assessment exercises can be formative or summative. Formative examples are more commonly employed and operate as a self-testing exercise that may be useful in reviewing and revising.

2.6 Comments and reflections on the teaching and learning process relevant to this work

The brief summary given in this chapter is intended only to introduce the topic, provide some background and define some of the key teaching and learning concepts relevant to this work. The fields of education and cognitive psychology have theorized extensively on aspects of teaching and learning and the reader is urged to consider a number of the texts referred to in this chapter for a more complete description of the topics.

Various methods of teaching and theories of learning have been presented and the debate between progressive and traditionalist educational practices has been outlined. Progressive and traditional tell-test approaches to teaching have been described with due emphasis on their benefits and limitations. Special regard was made to the limitations of both approaches since it is in seeking to investigate and address some of these limitations that this research is focussed.

The specific theories of Experiential Learning, Action Learning and Constructivism were explored due to their bearing on this work with their emphasis on *student focussed learning* and *learning by doing*. The difficulties and limitations in applying these types of progressive educational methods were discussed. One of the critical issues is in terms of the assessment of learning and this was briefly discussed along with descriptions of the standard assessment methods.

A brief review of E-Learning was given to illustrate the types or systems and methods that have been employed within this field. The rapid growth of this method of learning and some potential implications were described. This provides some context and background for specific research into the use of simulation and gaming as E-Learning methods that will be discussed in chapter 3.

3. Simulations, Games and their role in Civil Engineering and its Education

3.1 Background & Chapter Outline

This chapter reviews the use of simulations and games in a teaching and learning context. It is a broad topic with an extensive research record and this chapter can only provide an overview. It will concentrate on those aspects most directly related to the research programme but will give some background and history to the topic and define some of the key elements of the research area. A number of research projects and commercial products will be detailed to back up the theoretical arguments detailed.

Generic and fundamental issues in simulation and modelling will be initially described including discussion of the benefits and limitations, types of simulation, approaches to modelling and specific examples and case studies on the use of simulation. The topic of games will then be analysed in a similar manner with specific regard to computer based gaming leading onto a short discussion of the sub-domain of *simulation games* which combines elements of simulation and gaming and are commonly used for educational purposes

The use of simulations and games in a teaching and learning context will then be covered in depth. A number of case studies will be examined and the results from research analysing the effectiveness of simulations and games for learning will be reviewed. Issues in designing and using simulations and games for learning will be discussed along with particular attention to the integration of teaching, simulation and gaming requirements in the production of a simulation game that is most effective from a learning perspective.

More specific use of simulation games within the domain of civil engineering will be investigated. This will lead onto the primary field of interest to this research work; the use of management type simulation games in the domain of project management, and in particular construction project management.

3.2 Simulation and Modelling

Simulation can be defined as the act or process of mimicry or imitation or some physical or abstract system (OED). Modelling is the act of representing something, usually on a smaller or focused scale. Modelling is therefore a pre-requisite for the production of a simulation and a simulation is in effect an implementation of a model over time. Models could range from relatively simple diagrams and descriptions, mathematical formulae, complex maps and technical specifications and up to full three dimensional representations of a system - the colloquial definition of a model. A simulation is typically something which uses a model of some physical or abstract system to mimic its functioning for the purposes of analysis, optimisation, education, or even purely for entertainment.

The term simulation has become synonymous with computer based simulations in recent times due to the aptitude of computer systems in producing highly complex, detailed and accurate representations of some physical or abstract entity or process. The context of this thesis is primarily concerned with computer simulations and/or educational simulations. The role of simulation outside of these domains will not be further explored in this document though there are many reference sources which explore the history and use of simulations in more general terms.

The use and utility of computer based simulations has grown extensively since the widespread adoption of Personal Computer's in the 1980s. The rapid growth of the internet and its penetration into mainstream society has increased the potential for network-based multi-user simulations dramatically.

3.2.1 Benefits and limitations of the use of simulation

There are many benefits arising from the use of modelling and simulation. They range from the self-evident, such as the ability to test options without risk to the real system or the user, to the incidental (but important), such as discovering discrepancies in user opinions of a system when modelling. However, the history of simulation development is not without its share of failures and there are significant limitations to be aware of when modelling a system and developing a simulation of that system. Some of the most commonly highlighted gains from using simulation and modelling are listed and briefly described below:

- Identification of critical elements of a system – Simulation is commonly used to determine the weak or pinch points in a system in order to improve the system's overall performance or robustness. Examples of this would include; a manufacturing process simulation highlighting sub-processes that are limiting the overall system's output or a simulated fluvial system showing areas most benefitting from improved channel conveyance.
- Hypothesis testing – Simulations can be used to examine the effects of changes to a system that would be too expensive to implement safely, cost-effectively or practically in the real system. The impact of such changes can be fully evaluated

in the simulated environment to determine if the benefits derived outweigh the risks and costs of implementation.

- Training & Education – Simulations can be used as an effective training tool where actual experience is too costly or risky to be used for the purposes of training. This potential benefit of simulation is the primary interest of this thesis and is further discussed in section 3.5.
- Formal system definition – The modelling process used to produce a simulation involves the development of a detailed definition of the system or process being simulated. Producing this can provide great benefit in itself since it makes explicit many elements of a system or process that may have not being fully understood prior to the modelling process.
- Enabling complex system analysis – The use of simulation can allow users to examine complex interactions between system elements that cannot be easily analysed using other approaches. For example, examining the impact of changes to raw materials in terms of an overall manufacturing production process such as concrete production (Long et al, 2007)

The benefits described above must however, be placed in the context of the limitations and constraints of simulation and modelling techniques. The huge benefits of simulation do come at some cost and great care must be taken in the modelling and use of simulations if the potential benefits are to be realised. The major limitations related to the modelling and use of simulation in general are described below. Many of the issues highlighted are intrinsically related but have been listed separately to emphasise their importance:

- A simulation is only as realistic as the model on which it is based
- Complex systems are notoriously difficult to simulate accurately. It is often almost impossible to quantify accurately all the potential elements and interactions between those elements within the system boundaries.
- External effects and their impact on the system to be simulated must be accurately modelled but are often difficult to analyse and quantify.
- Unforeseen influences on a system cannot be easily simulated. This is related to the limitations already stated but worthy of specific note. It may be possible to generalise for events not explicitly defined in the model but it is not possible to accurately simulate events, interactions or effects that were not in the original model.
- Complex simulations require a large amount of processing cycles for their execution. Typical examples of this would include climate modelling simulations used in weather prediction or for assessing long term climate change and other large scale Computational Fluid Dynamic (CFD) models.

- In order to mitigate for the previous limitation, simulations will commonly omit elements not considered to be important or events not likely to occur to in order to improve execution time. This simplification is a compromise between accuracy and efficiency and will obviously limit the overall efficacy of the simulation to some degree.
- There is a risk that the simulation is treated as being 100% accurate and that too much reliance is placed on the results. Inherent errors and omissions of the model and simulation are often ignored. As with any scientific too, attention must be made to the limits of the tool and care should be taken in interpreting the results.
- By its very definition, a simulation is not the same as the system or process being modelled and is only a facsimile. Even the most accurate simulation based on the most detailed of models is not the same thing as the system or process it represents. There is always the potential for discrepancy between simulated and simulation.

Limitations specific to the use of simulation in a teaching and learning context are further discussed in section 3.5

3.2.2 Potential applications of simulation

Simulation, and in particular computer simulation, has a range of potential uses in a wide range of disciplines. In terms of the work undertaken as part of the research programme, it is the educational use as a learning tool that is of principal interest. However, it is relevant to this chapter to provide a brief description of other ways in which simulations can be employed. It is important to note that the various applications detailed are not mutually exclusive and many simulations will perform a range of the functions described to a greater or lesser degree depending on their specification.

3.2.2.1 Optimisation

One of the most common uses of computer simulations is to optimise a system or process. The repeated execution of a simulation can be used to examine the impact of change to specified variables on the simulation. By running the simulation through many iterations and across of variety of potential states an optimal solution in terms of the required variable (e.g. time, cost or safety) can be determined. Assuming the simulation was modelled with sufficient accuracy (and with due attention paid to the limitations of simulation as described in section 3.2.1), the simulated optimal solution should improve performance in the actual system.

Multi-objective optimisation algorithms can be employed within a simulation in order to produce an optimal solution in terms of a set of key variables. Since an optimising simulation outputs quantitative values that must closely match real world performance it requires a highly accurate simulation model in relation to the system or process simulated. This type of application is not suited to systems with large degrees of uncertainty and interactions outside the modelled boundaries. It is most appropriate for the modelling of controlled environments such as industrial facilities or electronic or mechanical systems.

3.2.2.2 Decision Support

Decision making and strategic planning for complex systems such as urban development, transport networks, financial markets, manufacturing facilities and construction projects are areas well suited to the use of simulation. Simulation can be employed to model a wide range of "what if" scenarios that could not be tested in the real world environment being modelled for reasons of practicality, safety or cost.

Simulations performing decision support functions and applications are often referred to as Decision Support Systems (DSS) though not all DSS systems are actually simulations in the classical sense. DSS are a class of computer systems specialising in knowledge management and decision making and many of them employ simulation in their operation

Simulation is a powerful tool in this type of computer system since it enables decision makers to examine a range of potential future scenarios and examine the impact of changes to the system on a range of measures and can also highlight unforeseen options and results that could not be easily identified through other techniques. It is not focussed on generating only the most optimal solution as with an optimising simulation but in providing a range of potential solutions to aid in the decision making process. A decision support simulation may also be capable of optimising behaviour but this will not be its primary function.

3.2.2.3 Forecasting

All simulations forecast future system behaviour as part of their inherent function but their ability to forecast is usually utilised for the purposes of optimisation, decision making, education or entertainment. Simulations specifically aimed at forecasting are what is being described in this section. This ability of a simulation to be used to forecast future changes to a system is widely used when simulating natural systems such as climate, flooding events or the movement and interaction of planetary bodies within the solar system.

By far, the most widely known application of simulation in forecasting would be in weather prediction – An internet search for the term "forecast" will return page after page of links to weather sites and related content. Meteorology was an early adopter of computer simulations for the purposes of modelling weather systems and forecasting future weather. The computer simulations used in weather prediction are some of the most complex and require the most powerful of computer systems and networks for their execution.

Predicting the future state of a system is heavily dependent on accurately modelling the system to a sufficient level of detail for the level of predictive accuracy required. Forecasting simulations may often employ a large set of historical data on system behaviour in order to verify the predictions made against similar previous events. Applications where forecasting is of use typically involve natural systems or those with high degrees of complexity and/or uncertainty. Forecasting the behaviour of simple and certain systems or processes would be a trivial task of calculation and not require the development of a complex system model and simulation.

Figure 3.1: NCAR simulation model used for earth climate modelling (taken from University Corporation for Atmospheric Research UCAR) http://www.ucar.edu/communications/ucar25/forecasts.html)

CFD simulations are typically used to predict the behaviour of natural systems or artificial structures under a variety of dynamic loadings caused by air or water flow. Examples would include testing the effects of wind shear on bridges or tall buildings and simulating the extent of inundation in a flooding event.

3.2.2.4 Education

The concept of using simulations as a method of teaching or training has been around for some time. For example, the original flight simulator was developed as far back as the 1930s (Prensky, 2001 p299). Simulation offers the ability for students to engage in a representation of the activity that they are attempting to learn without the risks associated with the actual task. It is also in the form of experiential learning which, as discussed in chapter two, has been shown to be a very effective method for teaching.

Since the introduction of computer based simulation in education there has been an apparently exponential increase in their use and availability. The range of educational simulations currently available is vast and includes a heterogeneous set of simulation types, subject domains, target level, complexity and length (amongst other factors). Many of the simulations used for educational purposes combine gaming elements (as described in section 3.3) and are referred to as *simulation games* or *serious games*. Educational simulations are discussed in much more depth in later sections of this chapter and will therefore not be further discussed at this point.

3.2.2.5 Entertainment/Recreation

The use of computer based simulations simply for the purposes of entertainment or recreation was not one envisaged by early creators of such systems. Initial use of simulations in this way was an unintended side effect of the engaging nature of such systems which soon led on to the development of simulations designed primarily for the purposes of entertainment. The use of educational and training simulations by learners was the primary source of introduction to simulation to people outside of specialised scientific and industrial backgrounds.

Similarly to educational simulations, those used for the purposes of entertainment are commonly referred to as *simulation games, strategy games* or *serious games* and a full description of these types of simulation is given in section 3.4 due to their direct relevance to this research.

3.2.3 Modelling methods and approaches

It is clearly evident that the modelling process used to develop a simulation is responsible to a large extent in the accuracy and utility of a simulation. There are a multitude of potential methods and techniques used to produce models for simulations including Basic Algebraic specifications, Flowcharts, Petri-Nets, Integrated DEFinition modelling (IDEF) and the Unified Modelling Language used primarily for modelling software systems. The choice of modelling method or language is highly dependent on the type and application of the simulation being produced and system being modelled. Whatever approach to model specification is followed, the general principle is to define the elements of a system in some primitive types that can be easily simulated computationally and to define all potential interactions between these primitive types in the functioning of the system being modelled.

In addition to the traditional approaches to simulation modelling using static models generated on paper or utilising diagrammatic software applications (e.g. Microsoft Office Visio software), increases in computational power have led to the generation and application of combined modelling and simulation environments such as Rockwell's *ARENA* and XJ Systems *AnyLogic* – see Figure 3.2 for an example.

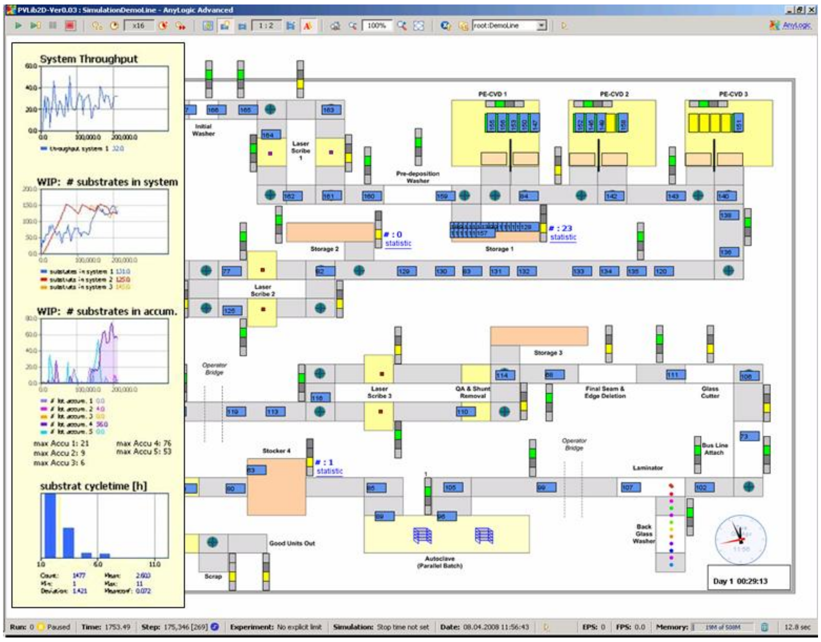


Figure 3.2 : Model produced using XJ Technologies AnyLogic simulation and modelling system (http://www.xjtek.com/anylogic)

3.2.4 Types and Properties of Computer based Simulation

The discussion to date has briefly described the potential benefits, limitations, applications and modelling methods in relation to computer based simulation. Before providing some examples of simulations in order to illustrate the points made and those relevant to later discussion and the research in general it is important to classify the types and properties of typical simulations.

Banks and Carson (Banks & Carson, 1984) provide a more detailed and thorough explanation of the types of simulation than can be given here and provide the details for much of the brief explanation of types listed in the following sub-sections.

3.2.4.1 Discrete vs. Continuous and Monte Carlo Simulation

A Discrete Event Simulation (DES) progresses in time step intervals and the state of the simulation is updated at each time step. In comparison, in a continuous simulation the variables are all continuous functions such as differential or Navier-Stokes equations. It is important to note that the simulated time in both types of simulation can progress at whatever rate is defined in the simulation or set by the user. It should also be pointed out that a truly continuous simulation is not strictly possible on a digital computer (though it would be on an analogue computer) as programmes are executed in discrete intervals of processor time. Continuous simulations are commonly used to model flow-based applications such as CFD models.

DES is generally the more popular type since it can be applied in a wider range of applications. DES utilise a clock function to represent the internal time of the simulation. This clock could be advanced manually by the user or automatically by the simulation itself. The time step used in a DES could be fixed or non-fixed. Fixed time steps mean each time the simulation is advanced, a fixed period of time is added to the simulation clock (e.g. second, minute, day or week) and is by far the most common type of DES. A non-fixed DES would advance until a specified event is completed. This is more suited to simulating activities that do not have fixed durations and cannot be terminated until they are completed (non-splittable). An example of this would be the pouring of concrete on a construction site where duration would be variable and the process cannot be stopped in mid-pour. Please note, that non-splittable activities can still be simulated in a fixed timestep DES just as splittable activities could be modelled using a non-fixed timestep simulation.

DES utilises random variables (created using a pseudorandom number generator algorithms) in order to model the inherent uncertainties of any system. A list of outstanding events will also be required which is updated as the simulation progresses. Completion of all events on the list represents completion of the simulation. Note that new events can be added to this list during execution in many simulation models (though not all).

It is possible to create a simulation that employs both discrete event and continuous algorithms or models in the same simulation. These are typically referred to as hybrid or combined simulations (Schwetman, 1978) and have obvious applications where the system being modelled contains a sequence of events and activities, some of which operate as a continuous flow of materials or information. Schwetman (Schwetman, 1978) gives an example of a hybrid simulation employing both discrete and continuous elements (mathematical models) in its underlying structure and demonstrates how this model can be more effective than a traditional DES.

As referred to in the title of this section, there is another type of simulation which cannot be classified as being discrete or continuous – Monte Carlo Simulation. Monte Carlo Simulation (Metropolis, 1987; Hammersley & Handscomb, 1975) is a stochastic process for solving non-probabilistic problems. It differs from a traditional simulation in that it keeps no internal temporal state and is sometimes referred to as a method rather than a simulation. Monte Carlo methods are well suited to predicting the potential variability in a system or process and are commonly used in applications such as risk management, project planning and oil exploration.

Monte Carlo Simulation works by defining a set of input variables, modelling the distribution of the input variables using random number generation and then calculating the required outputs based on the randomly assigned input variables. The outputs are then added to the set of results and the process is repeated for a defined number of iterations in order to achieve a sufficiently robust overall distribution of potential outputs.

3.2.4.2 Stochastic vs. Deterministic

In the simplest of terms a stochastic simulation has random elements and can produce a different result each time it is run whereas a deterministic simulation will produce the same result for a given set of inputs. The difference between stochastic and deterministic types of simulation is more of a continuum than two completely separate types. Simulations will commonly utilise a combination of stochastic and deterministic elements. For example, in a flight simulator the aircraft modelled will work deterministically each time (unless failure of the aircraft systems is a risk being simulated) but the environmental factors such as weather and wind speed may be randomly defined for each flight.

A stochastic simulation will be more useful in analysing risk and uncertainty but is prone to producing inaccurate results due to the inherent uncertainty of the stochastic elements of the simulation. It is essential that the random distributions of stochastic elements be carefully analysed and defined in the modelling process and be suitable for the application to which the simulation is to be assigned. Since the input variables to a stochastic simulation are random it follows that the outputs of such a system will also have a random element and should be treated as statistical estimates, even though they may be very reliable and accurate estimates.

Deterministic simulations are far more consistent in their results and can be used to perform sensitivity analysis without the randomness of variables influencing the result.

3.2.4.3 Steady state vs. Dynamic

Steady State simulations use a fixed system model and use a well defined set of input variables. The simulation is run iteratively until an equilibrium point is found. Steady state models are typically used to model natural physical systems and often employed in simulating chemical plant processes. Steady State simulations are often created and used prior to the development of a more complex dynamic simulation in order to check the data collected as part of the system modelling process and to highlight critical aspects of the system in operation. Due to their fixed structure, steady state simulations are easier to model and implement than a more complex, dynamic model. In many applications, especially in relation to simple processes and independent systems, a steady state simulation is the most effective and efficient solution.

Dynamic simulations, as their name implies, enable changes to the system simulated due to changes in the input variables. The design and development of a dynamic simulation is more complex and time consuming than the equivalent steady state solution but produces a more flexible and adaptive simulation.

An example of a dynamic simulation would be the physics engine software (e.g. Havok) used in a range of academic and commercial applications in recent years. Such systems can be used to model the effects of interaction between physical elements realistically without the need for explicitly scripting or coding the behaviour for all potential instances of interaction. It can be used to calculate the final positions and damage to two vehicles colliding based on a heterogeneous set of crash conditions which could ultimately be useful in safety simulations for a motor vehicle manufacturer or for use in a video game. Note that the *realism* of outputs produced from the simulated collision would be likely to differ greatly for in each instance postulated. More discussion of the relationship between simulated realism and gameplay requirements will be detailed later in the chapter (section 3.3.5).

Like many of the properties and types of simulation discussed in section 3.2.4, in actuality simulations can adopt a position on the spectrum between fully steady state and fully dynamic rather than the distinction between steady state and dynamic being Boolean options. In the modelling phase, a developer will determine the appropriate aspects of the simulation for full dynamic simulation and those that can be modelled using a steady state approach. Alternatively, the developer may decide to build a steady state simulation initially as a prototyping or research exercise and then create a dynamic simulation based on the findings from the steady state model.

3.2.4.4 Distributed versus Local

Local simulation is executed on a single computer using only the processing capability of that computer. A local simulation may require a network or internet connection in order to access resources used in the simulation but does not use networked processing capabilities in order to execute the simulation.

In contrast, a distributed simulation is run across a network of computers (could be via LAN, Intranet, Extranet or Internet). Usually a central file server acts to manage the distributed execution of the simulation and be used as a source of data and repository of results. The primary reason for using a distributed simulation over a local simulation is processing power. Large and complex simulations notoriously require huge amounts of processing power. For example, one of the most powerful supercomputer networks in the UK is owned by the Meteorological Office for the purposes of running their climate simulations for weather prediction.

Distributed simulation is a method that has gained popularity and use since the advent of the internet and high speed computer networks. It has the potential to greatly increase the processing power of a computer system without the cost of utilising the state of the art in high performance processors. The underlying methods for executing a simulation in a distributed manner are of technical interest but are not relevant to this thesis. To briefly summarise, the simulated problem can be broken down into a large number of sub-problems which are then run by separate processors or computers. Alternatively, distributed processing power can be utilised to run a large number of iterations of a simulation concurrently. This enables the collection of a large dataset of results that would require a huge amount of processing time if executed linearly on a single computer. This type of method for distributed simulation is commonly used via the internet in the processing of huge datasets employing thousands of PCs. The simulation is run as a screen saver when the user is not using the PC and well known examples would include the SETI project.

It should be mentioned that a distributed simulation obviously requires additional resources for the management, transmission and collation of simulation data over the computer network. It is only used where necessary due to processing limitations or temporal constraints in running a simulation locally.

3.3 Games

There are many definitions of what exactly constitutes “a game” (e.g. Prensky, 2001; Gee, 2003). All definitions agree that a game is some form of structured or organised activity that involves play and is generally for the purposes of entertainment. Games differ from work in that they are not generally played for remuneration, though games involving gambling and professional game players such as sportsmen or women would be an exception. They also differentiate themselves from pastimes due to their needs for rules or objectives and their explicit structure or organisation.

Research on human behaviour and learning has identified the important role that games and play have in the development and learning in early childhood (Piaget, 1952) and also hypothesises on their utility throughout life in terms of learning. The specific issue of learning through the use of games is further investigated in section 3.5 onwards.

The range of potential game types is immense and includes physical activities such as sports to more abstract mental games such as chess. Games can include elements of competition or collaboration and can be played solo or in groups. Variability in game complexity is vast ranging from the most simplistic, e.g. noughts and crosses (or tic-tac-toe for US readers), to the more intricate, e.g. chess, bridge or role-playing games with rules books spanning many volumes. Complexity in rules and design is different to complexity in gameplay (see section 3.4.1) itself. Games such as Go and Risk are relatively simple in terms of the rules governing play but are very complex in terms of the underlying strategy attached to playing the game well.

3.3.1 Game Properties and Terminology

The broad range of potential games and styles of play makes it difficult to produce a detailed and specific study of game properties and the terminology commonly used in relation to games here. A selection of those properties of interest to this work is listed below:

- Gameplay – the experience of playing the game. Gameplay combines the structure of play and the interaction between player and game. It is also commonly used to describe how enjoyable the game is to play and to describe the type of play involved.
- Rules – The constraints on the player enforced by the game and the method by which the game is advanced.

- Difficulty – The level of challenge offered by the game. It is not always easy to standardise the difficulty of a game since it is highly dependent on the relative skill level of the player. The difficulty curve of a game is used to describe how difficulty changes throughout the gameplay. A difficulty spike is a term used to describe a point during gameplay where the difficulty is much higher than at other points. Such spikes in difficulty are frustrating to players and are to be avoided through good game design.
- Strategy – This is the method employed by the player during gameplay. It is analogous to an individual's learning style in a learning process
- Game AI – This refers to the methods used by the game to simulate the behaviour of non player characters within the game.
- Multiplayer – A term used to describe games where more than one player can participate in the gameplay. Multiplayer games can be either competitive or collaborative experiences.
- Agency – The ability of the player to affect change within the game. It also can refer to the link between a player's action and the games response. A player's agency is typically high to avoid frustration but will be limited to some degree in order to make the game 'realistic' and challenging. This is of particular interest in simulation games and a good description of the role of agency in this context is described by Poole (Poole, 2009)

3.3.2 Digital Games

Up to this point in section 3.3 the discussion has been generic in nature and could be applied to many types and formats of game. However, referring back to the original objectives of the research given in Chapter One it is clear that the aim of this thesis is to investigate the utility of computer simulations and games in terms of learning. Therefore, the remainder of this section will provide background and computer based games or more specifically, *digital games.*

Digital Games includes all games that can be played on a computer, games console or handheld gaming device and are often referred to colloquially as *video games*. The history of digital gaming dates back to early mainframe computers (the PDP-1 mainframe to be specific) and the development of a game (SpaceWar) as a hobby by academic research staff. Poole and Hertz (Poole, 2000; Hertz, 1997) all describe the history and evolution of digital games from their initial amateur subversion of academic equipment to a global industry generating billions of pounds and rivalling television and film as an entertainment source, particularly for the male youth demographic (BBC, 2005).

3.3.3 A Taxonomy of Digital Games

The rapid growth of digital games has led to the development of a number of specific gaming genres and subgenres. Due to technological advances and the industry's relative infancy, new game types or subtypes are being created regularly. Prensky (Prensky, 2001) describes a general taxonomy of games in his book, *Digital Game Based Learning*, which is shown below with some adaptation and extension by the author to reflect the specific requirements of this research and changes in digital games culture since 2001. Note that there are many other games classification taxonomies in existence, see Schiffler (Schiffler, 2006) for example, but the one shown in figure 3.3 is sufficient for the needs of this review of digital gaming.

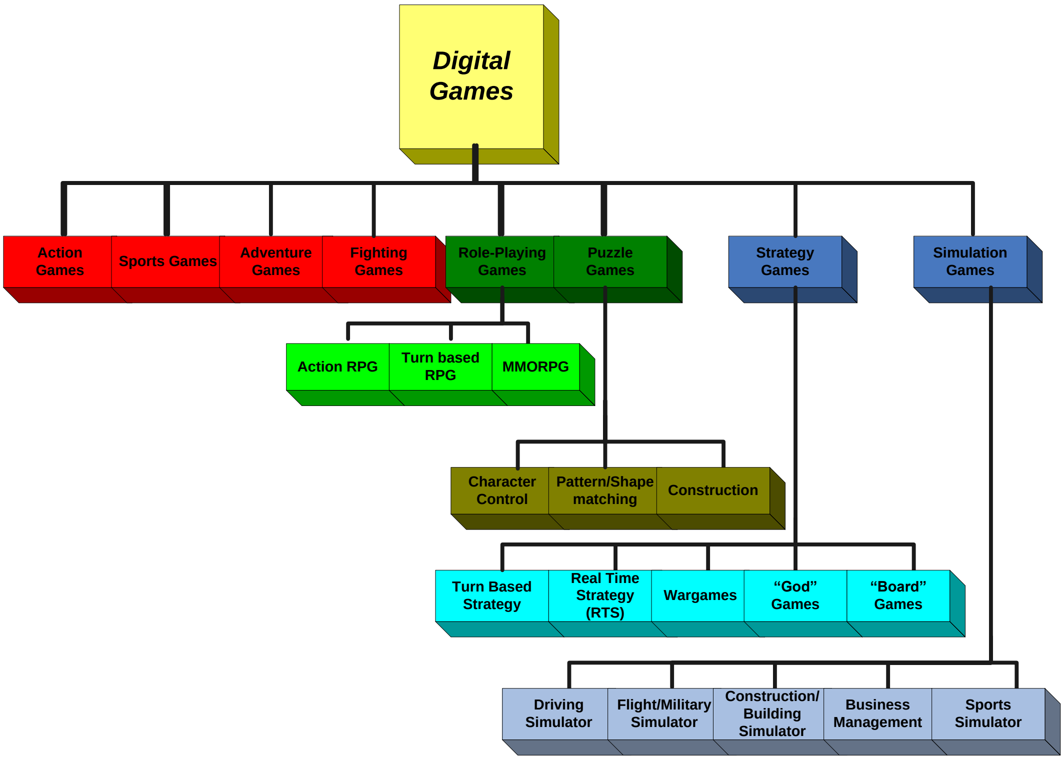


Figure 3.3 : Taxonomy of Digital Games - expansion of Prensky (Prensky, 2001 p129)

In the context of this work, it is not necessary to further describe most of the game types shown in Figure 3.3 but descriptions can be found in Prensky (Prensky, 2001) for readers interested in digital game types. The first tier of game types shown in Figure 3.3 represent those identified by Prensky and additional tiers are an expansion of the taxonomy relevant to this research. Blue links indicate properties and black links show sub-type relationships. Note that the choice of colour in the top tier of the taxonomy is to group game types of specific importance to this research. Those shown in red are of little to no interest; green indicates game types with some relevance and blue highlights the types of game highly relevant to the work outlined in this thesis.

The expansion of the taxonomy has concentrated on those game types relevant to the research only. Game types excluded and shown in red could be easily expanded upon in a similar fashion. For example, *Action Games* could be divided into *2 Dimensional Shooters*, *First Person Shooters*, *Third Person Shooters*, etc. The game types of specific interest to this work will now be further described.

3.3.3.1 Puzzle Games

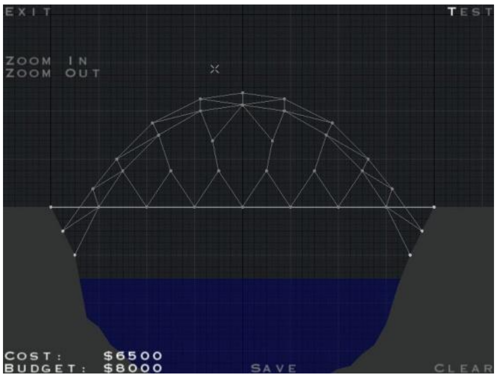


Figure 3.4: BridgeBuilder game (Chronic Logic, 2000)

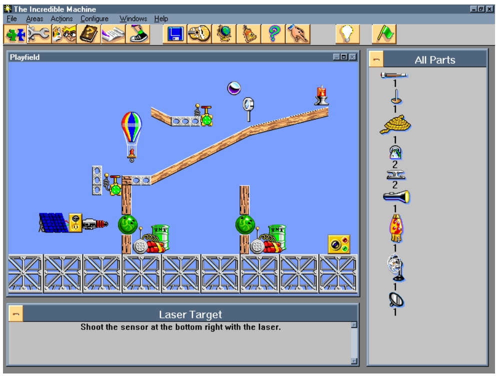


Figure 3.5 : The Incredible Machine game (Dynamix, 1993)

This category Includes simple two dimensional pattern or block matching games (e.g. *Tetris*) , complex multi-dimensional modelling and construction puzzles (e.g. *Bridge Builder*, *The Incredible Machine* series), character control puzzles (e.g. *Lemmings)* and assorted subtypes. The construction type puzzles are of particular interest in terms of the research aims of this work and will be further referred to in the relevant later sections of the chapter (section 3.5 onwards). Real time puzzle games require the player to solve the puzzle within temporal constraints which could be a simple clock countdown or environmental changes. Turn based puzzles are static and control of puzzle state is determined by the player(s), which could be human player and/or AI. Turn based games could still employ a time constraint in the form of a time limit for each game turn used to speed up play in a similar way to the use of a clock in Chess.

3.3.3.2 Role Playing Games (RPG)

In an RPG game the player controls a character or group of characters and undertakes some task or series of tasks according to an in-game narrative to reach some specified objective or end point. As tasks are completed the player character(s) gain experience points which can then be used to upgrade the character(s) attributes in a variety of ways. Tasks typically get more difficult during gameplay which necessitates this upgrading of characters in order to complete the task. Action RPG's (e.g. Fallout 3, Oblivion) play in real time and can look similar to (and be classified as) Action Games. Turn based RPG's (e.g. Final Fantasy Series) typically work like a board game in combat with players and AI controlled enemies taking turns for movement and attack based on their specific characteristics. Massively Multiplayer Online RPGs or MMORPGs (e.g. World of Warcraft, EVE Online) combine RPG elements with social interaction in large game worlds running on central servers and accessed by client software on each player's computer. RPG type games are not in themselves commonly used in an educational context but elements of RPG gameplay such as the link to an in-game avatar and the upgrading of that avatar could be potentially useful in an educational context.

3.3.3.3 Strategy Games

Figure 3.6: Screenshot from computer version of Carcassonne board game (Sierra Online, 2007)

Figure 3.7 : Screenshot from Empire Total War game (Creative Assembly, 2009)

Digital strategy games have much in common with strategy board games such as Chess, Risk, Settlers of Catan and Carcassonne. Players control a set of units with specified properties and use them to achieve game objectives (e.g. winning a battle or controlling the map). Strategy games are either Turn Based or Real Time Strategy (often referred to as RTS games). Turn based strategy games are very similar to the board games from which they were developed often employing a gridded or hexagonal game board where players and AI move games pieces turn by turn until victory or defeat conditions are reached. In RTS games, all players and AI move their pieces synchronously and generally are tasked with the collection and management of resources which enables players to purchase additional units and/or upgrade units. Strategy games can be classified into three distinct categories:

- Wargames – The most common type of strategy game, found in both turn based and RTS forms. Can range from games modelling entire military campaigns to small skirmishes. Examples of a strategy wargame would be the *Total War* series of games created by UK developer, *the Creative Assembly*, these include both turn based management for empire building and RTS for battles including dozens of onscreen units fully modelled in 3D battlefields.

- "God" Games – A subgenre of the strategy game where the player acts as an unseen all powerful entity controlling units and elements of the game world from above. An early example of the "God" game was *Populous* or *Little Computer People* and a more recent example would be *The Sims 3.* God games are usually RTS games. There is some debate as to whether God games are in fact strategy games or construction/building simulation games and the difference between the two game types is quite indistinct but seems to be based on the degree of strategic thinking required.
- "Board" Games – Digital versions of existing board games or new games that utilise a board game like approach to their gameplay. Digital board games are, in the majority, turn-based games reflecting their board game heritage (or inspiration).

3.3.3.4 Simulation Games

The specific game type of interest to this research work and described in depth later in this chapter (section 3.4)

3.3.3.5 Hybrid Games

In all attempts to classify there is likely to be exceptions to the rules applied. The rapid development and rate of change in the field of digital gaming makes all attempts to develop a fully encompassing taxonomy almost impossible. There are many examples of hybrid games that fall into a number of the game type categories shown in figure 3.4, e.g. the introduction of RPG elements into strategy games whereby player units can be permanently upgraded and improved during gameplay. New genres or subgenres are created on a semi-regular basis such as the recent growth in the rhythm action games (known collectively as *bemani* in Japan where they originated) such as *Guitar Hero*®, Rock *Band*® or *Dance Dance Revolution*™. However, the taxonomy proposed is of sufficiently generic nature to enable the incorporation of new genres in most instances. In the case of rhythm action games they would be classified as a subtype of Puzzle Games.

3.3.4 Engagement in Digital Games – Flow, Immersion and Balance

It is clearly evident from anecdotal evidence and social surveys that players of digital games find them to be highly engaging. It is no great surprise that children generally prefer playing games to doing their homework. However, for the purposes of this research it is important to assess why this is the case and fully explore the nature of the engagement created when using digital games.

Digital games often require complex planning and thinking by the player and can be as, if not more, cognitively challenging than many teaching exercises. It should also be mentioned that the vast majority of digital games offer little in the way of cognitive development and simply provide entertainment. Multiplayer games often require effective team work, communication and collaboration skills which, as will be discussed in section 3.9, are noted as a key requirement of industry in terms of graduate skills and are often not easily imparted through traditional teaching approaches. If digital games can provide learning and skills development whilst engaging the player in the learning process then it is important to identify the mechanism by which this is achieved.

Examining the engaging nature of digital games has identified the key concepts involved in maintaining player engagement. Simple escapism from the routine of daily life such as school or work are an obvious reason why games are engaging as with any other hobby or pastime. Three other major elements in engaging the player are flow, immersion and balance each of which will now be further discussed.

3.3.4.1 Flow

Csikszentmihaly (Csikszentmihaly, 1991) in his book, *Flow: The Psychology of Optimal Experience,* describes the state of flow where a practitioner in some activity, be it gaming, sports, working or learning, experiences a period of intense concentration where tasks can be performed more easily and enjoyably. Players of Digital Games report experiencing this phenomenon regularly and it is thought to be one of the primary reasons for the high levels of engagement with digital gaming. Prensky (Prensky, 2001) discusses how flow can be useful in educational games and highlights the issue of maintaining this state of flow in players during gameplay.

> *"The trick with flow is to keep someone in this state. Make things too easy and players become bored and stop. Make things too hard and they stop because they become frustrated. Well-designed games are especially good at maintaining this flow state in players and games designers have developed special techniques to do this..."*

(Prensky, 2001 p124)

Matching game difficulty to player ability is seen to be the principal component in establishing flow although obviously the task being undertaken must be sufficiently entertaining or of interest to the player in the first place.

3.3.4.2 Immersion

Immersion within the gaming environment, be it a fully 3D environment or a more simple menu based system, is a critical aspect in player engagement. It refers to a state where the player's full concentration is focused on playing the game and is therefore related to the concept of flow previously discussed. It differs from flow in that it is concerned with the integrity of the gaming environment and its function rather than with the level of game difficulty

Cheng and Cairns (Cheng & Cairns, 2005) examine immersion in a gaming environment and test the theory that the coherence of the in-game experience is a key element in creating immersion. They found that immersion, once established can be maintained even if the coherence of the in-game environment is decreased.

3.3.4.3 Game Balancing

Game balance is closely linked to the concept of flow described in section 3.3.4.1. It refers to the process of ensuring that the gameplay is adapted to maximise the player's experience. It includes the balancing of game difficulty and challenge required for flow to occur but also includes the inclusion of different gameplay styles in order to maintain player interest throughout gameplay.

3.3.5 Educational Digital Games

Games have a long history of use in education, especially in the early years teaching of children. Piaget (Piaget, 1952) in particular is famous for his early work in investigating the role of playing games in children's development and learning. In terms of digital games, there has been a chequered history relating to their use in education. Digital games have long being accused of distracting children (and adults) from their learning and parents will commonly have issues with their children playing digital games when they should be completing their homework. Digital games have been used in education since the introduction of computers into the classroom in the late 1970s/early 1980s. Early games were commonly automated versions of simple tests and quizzes that used the graphical style and simplified gameplay of early digital games. Early versions of the *Math Blaster*! Software described in table 3.1 is typical of initial attempts at educational digital games.

Educational digital games are sometimes referred to collectively as *Edutainment* or *Serious Games* and early examples in the genre include *"Where in* *the world is Carmen Sandiego"* (Broderbund Software, 1985) and *"Mavis Beacon Teaches Typing"* (Broderbund software, 1987). The first of these examples was a very successful game for teaching basic geography, history and trivia to schoolchildren and the second, a tool for teaching touch typing now in its 17th version and still widely used. Figure 3.8 and Figure 3.9 show screenshots from the two games.

The majority of early educational games were aimed at teaching numeracy, literacy and other basic skills to children. Similarly to early digital games, many of these were simply digital versions of existing teaching materials. Prensky (Prensky, 2001) provides a summary of the history of educational games and the reader is directed to these if interested further in the history of this subject.

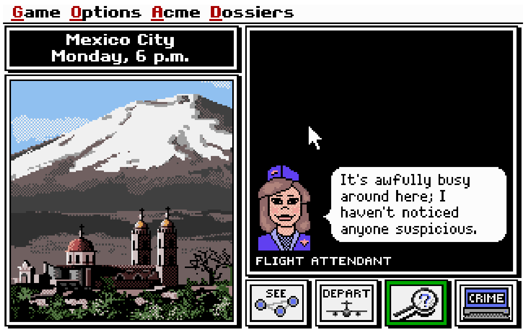


Figure 3.8 : Screenshot from "Where in the world in Carmen Sandiego"

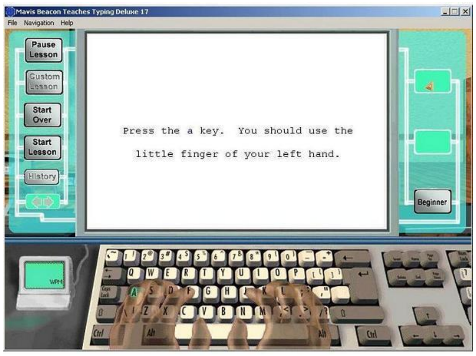


Figure 3.9 : Screenshot from Mavis Beacon teaches touch typing

In addition to games specifically designed for educational purposes, existing games have often being co-opted for the purposes of learning. *SimCity,* (Maxis Software, 1989) is the most obvious example and has being employed for the purpose of teaching children the fundamental issues in urban planning though it was originally released purely as an entertainment product. More recent examples of edutainment, educational or serious games are described and categorised in table 3.1.

Although there have been many successful attempts at combining digital games and educational content, including those described and referred to in this section, there is a wide perception that *"educational games suck"* (Herz, 1997). It is not known whether the introduction of educational content into digital games reduces their engagement or it is simply that educational games are often not well designed digital games. The latter is certainly the majority view of researchers and developers working in this area (Prensky, 2001; Gee, 2003; Squire, 2005; Aldritch, 2003) and the fact that numerous effective examples of Educational Digital Games do exist, backs up this hypothesis.

Title	Developed	Subject	Description
Democracy	Positech Games, 2005	Politics & Government	Government simulation game in which the player takes on the role of president of a democracy and must determine policy in a number of key areas such as taxation and social welfare. Player aims to keep various citizens groups happy in order to be re-elected.
Food Force	UN World Food Programme (UNFWP), 2005	Famine Relief, Food Distribution	A *serious game* aimed at educating players regarding the role of the UNFWP in disaster aid and famine relief. Uses a suite of small arcade style games to illustrate different elements of the UNFWP's role.
Dr Kawashima's Brain Training: How old is your Brain?	Nintendo, 2005	Numeracy, Literacy and Memory	Very successful game marketed as a tool for improving brain performance by repetition of simple games of literacy, numeracy and memory tasks.
PeaceMaker	ImpactGames, 2007	Geopolitics, Conflict resolution	Turn based strategy/simulation game modelling the current Israeli/Palestine conflict. Players can play as both sides and attempt to create a peaceful resolution to the conflict
Math Blaster!	Davidson & Associates, 1987-Present	Basic numeracy	A long running series of games for teaching basic numeracy to children (<10yrs). Uses the form and structure of typical arcade games in order to answer questions of basic arithmetic.
The Typing of the Dead	Sega, 2000	Typing	A curious combination of an existing zombie shooting game with a typing trainer. Requires the player to type words or phrases displayed on screen quickly and accurately in order to defeat attacking zombies. Based on an existing action game engine from the *House of the Dead* series

Table 3.1: Examples of recent Educational Digital Games

3.4 Simulation Games

As the name suggests, simulation games combine elements of simulation and gaming to produce an (intentionally) entertaining simulation or a *realistic* game. Realism defined as being in terms of the model of reality offered by the simulation aspect of the simulation game obviously. Prensky (Prensky, 2001 pp210-221) extensively discussed the relationship between simulations and games and what is required to turn a simulation into a simulation game. One of the main changes identified between a simulation and a simulation game is the introduction of specific objectives and the potential to *win* or complete the simulation game. The introduction of challenge and reduction in realism of the simulated environment are other common differences. For example, a flight simulator will realistically model the experience of flying an aircraft including all those aspects of flying that are quite boring such as making a flight plan, communicating with ground control and long periods of level and uneventful flight. A flight simulator game will typically focus on a more action based approach to flying a plane such as flying a military jet in combat. It may well reduce or alter the physics of flying a plane to allow manoeuvres that would not be possible in a real aircraft but increase the fun of flying a plane.

A simulation game inherits many of the properties, limitations and benefits of both simulations and games. The balance between simulation and gaming elements within a simulation game is a critical measure of its potential applications and capabilities. Many simulation games allow the user to specify the degree of simulation within the simulation game. This can allow them to add or restrict aspects of the simulation for the purposes of entertainment or to alter the difficulty of the simulation game. Typical examples of this would be driver assists in a driving/racing simulator, Forza Motorsport 2 (Microsoft, 2007) allows the player to add a visualisation of the correct racing line and speed to the display. This is not realistic in terms of simulating real world racing but makes the game less frustrating for novices.

The major types of simulation game were shown in Figure 3.3. Those of direct relevance to this work will now be discussed in more depth.

3.4.1 Management Simulation Games

The field of management is one that has been well served by simulations games. There are a wide range of games available within this context and it is an area well suited to their use for a number of reasons including:

- Management is a practical skill which is suited to experiential learning.
- Actual experience of management in the real world is not practical for teaching purposes for most students.
- It is a field where traditional teaching approaches are limited in their ability to create effective learning.
- Simulation and games can be used to test out various theories and management approaches without cost.
- They are highly suited to examining decision making processes which are a critical aspect of management

It is not practical to provide a full discussion of management simulation games within this section but Gilgeous and D’Cruz (Gilgeous & D’Cruz, 1996) provide an excellent review of the subject and the reasons why simulation games are an effective teaching method for management. John Sterman from MIT (Sterman, 1992) discusses the role of simulation games in management and coins the phrase *Management Flight Simulators* in a well cited paper on this subject.

Numerous examples of management simulation games exist and range from those with a more game focussed approach (Railroad Tycoon, Capitalism) to those that are complex and detailed simulations of management processes (VLeader). A large number of management simulation games, particularly business management games, are commercial products designed for industrial training purposes rather than academic learning.

3.4.2 Construction and Management Simulator (CMS)

CMSs are a type of simulation game that focuses on the building, management and expansion of simulated projects or communities through the allocation of a constrained resource set. Like management simulation games they differ from traditional games in that they do not have a fixed win condition and are often open-ended games where no defined end state can be achieved. Some enable the definition of scenarios with specific goals and objectives and can be 'completed' by the player.

A wide range of examples of this type of simulation exist and range from recreational games to teaching tools. Some can be used as both (e.g. SimCity).

3.5 Simulation & Games for Learning

As described in chapter One, the use of simulations and games in the field of teaching and learning is well established and discussed though there is still much debate as to the extent of their efficacy in this role. In this section, the case for and against the use of simulations and games in learning will be discussed and illustrated with a number of examples of educational simulations and games. Simulation and gaming have been used in teaching for some time. Depending on the exact definition used, it could be argued that its use predates modern schooling since simulated environments in military training have been in existence since ancient times. Games for the purposes of teaching skills and knowledge date back similarly. However, for the purpose of this work we are primarily referring to computer based simulations and games though some examples of early board games and role playing exercises for learning will be referenced to in this section.

The modern use of computer based simulation and gaming in an educational context can be traced back to the large body of research undertaken in the 1960s and 1970s. Advocates of utilising simulation and gaming in education put forward a range of arguments for their validity and utility. Each of the major points made will now be detailed:

- More engaging than the tell-test approach
- Provides learning that cannot be easily transmitted through traditional approaches

- Suited to the "gaming generation", i.e. those who are familiar with the use of games and simulations.
- Enables experiential and constructivist learning to be carried out.
- Is a form of student centred learning

Other arguments have been outlined for using games and simulations have been proposed but those listed above are most relevant to this work and to the *simulation games* game type. However, there are many critics of the use of simulations and games in education who raise a number of issues regarding their usefulness including those who see no validity in their educational use. A summary of the main arguments against their use will now be provided:

- Ludological Fallacy – There is not necessarily any link between performance at a game or simulation and ability at the actual activity or process. It may also be detrimental to learning since it provides a misleading view of the actual activity or experience.
- Provides potentially broad but very shallow learning
- Do not encourage reflection in themselves
- Unproven learning value (e.g. BBC "learning games do not boost results", 26 November, 2001)
- Enjoyment does not equal useful
- Too time consuming and resource hungry
- Difficult to assess learning through games and simulations
- Most educational simulations and games are poor

Most of the arguments against the use of simulation and games for learning are more of an argument against the ineffective use of games and simulations for learning either due to poorly designed examples or due to inappropriate application of them in teaching terms. Those arguing against their use in all instances now form a small minority in academic circles. Evidence of this can be found in a number of studies (e.g. Randel et al, 1992). There is still a large percentage of teaching staff who question whether simulations and games are more effective, or even as effective, as traditional teaching methods and there is definitely a need for further research in this area. This research aims to investigate the utility of simulation games in teaching and is part of a body of existing and ongoing research in this area.

Practitioners in using simulation and gaming in teaching and learning argue that this requirement for absolute incontrovertible evidence of their effectiveness is not matched by a similar need to confirm the appropriateness of traditional teaching methods and that there is plenty of evidence that traditional teaching methods can be ineffective in teaching specific types of knowledge and for certain types of learner.

The fact that traditional teaching is not fully proven either is no reason not to fully investigate the practicality of using simulation and gaming in teaching but it is an important point to make. It is not practical to discuss the arguments for and against the use of simulation and gaming in education further here but it can be concluded by stating that their use has been successful in a large number of studies and there is significant precedent for their inclusion as a valid teaching method. It is fair to state that there is a requirement for further evaluation of their efficacy in teaching and that this research aims to add to that evaluation.

3.5.1 Educational Simulations

The use of simulation in an educational context enables students to experience aspects of their field of study that were be too costly or dangerous to experience in person. It provides students with an opportunity to examine the impact of their decisions on a model of a system they are learning about. Simulation can be useful in transmitting procedural knowledge that is not easily taught through a traditional tell-test approach. In some instances (especially military and pilot training) simulation is the only viable option for teaching.

Care must be taken to ensure that the learning outcomes can be achieved using simulation and the use of simulation does not negate the need for effective teaching support. Simulations, and games as will be discussed in the following section, do not encourage reflection as part of their core function. As discussed in chapter 2, reflection is a critical part of the learning cycle and other teaching methods must be used in order to ensure that the learner reflects on their simulated experience. Typically this is achieved by the use of debriefing sessions or classes where learners are required to present or discuss their simulated experience and reflect on their performance at the simulation and how this might relate to the real world experience being simulated. Another option to encourage reflection could include the requirement to produce a report or piece of coursework based on the learner's experience of using the simulation.

3.5.2 Educational Games

Educational games were described as part of the discussion on games in section 3.3.5 and will only be briefly discussed again here for the purposes of clarity. The main motivation and benefit of combining digital games and with educational content is to increase the learner's engagement with the learning material. It also enables the learner to engage in self-directed learning which can be very effective as was discussed in chapter 2. There have been a number of successful educational games some of which were described in section 3.3.5.

An example of a relatively simple educational game for engineering is *Tree Trumps* and is shown in Figure 3.10. The game was developed by Dr Ridley-Ellis from the Centre for Timber Engineering at Edinburgh Napier University in the UK and is available to play on their website (Ridley-Ellis & Caver, 2007)

Figure 3.10: Screenshot from the *Tree Trumps* game (online here)

Gameplay copies the *Top Trumps* formula popularised in the 1970s. The player is dealt a number of cards from a pack and attempts to win the cards of other players (computer controlled or human players). The player goes through each card in their set in sequential order and selects a specific property from their current card that they believe will be higher than the corresponding property on their opponent(s) card. The player with the highest value for that property gets to keep their opponent(s) current card. The game ends when a player has collected all the cards.

In Tree Trumps each card represents a particular type of timber and contains values for a set of properties relevant to construction using that material. The game is an engaging way for students to learn the key properties for timber construction materials. A recent paper by Ridley-Ellis (Ridley-Ellis, 2008) provides a more detailed description of the game and its educational value.

3.5.3 Educational Simulation Games

Simulation games are ideally suited to be used as educational tools due to their combination of experiential learning and engaging gameplay. Aldritch (Aldrich, 2004) provides a good discussion of the essential criteria in the development of educational simulations and games and discusses the challenges in balancing the gaming, simulation and pedagogic elements involved.

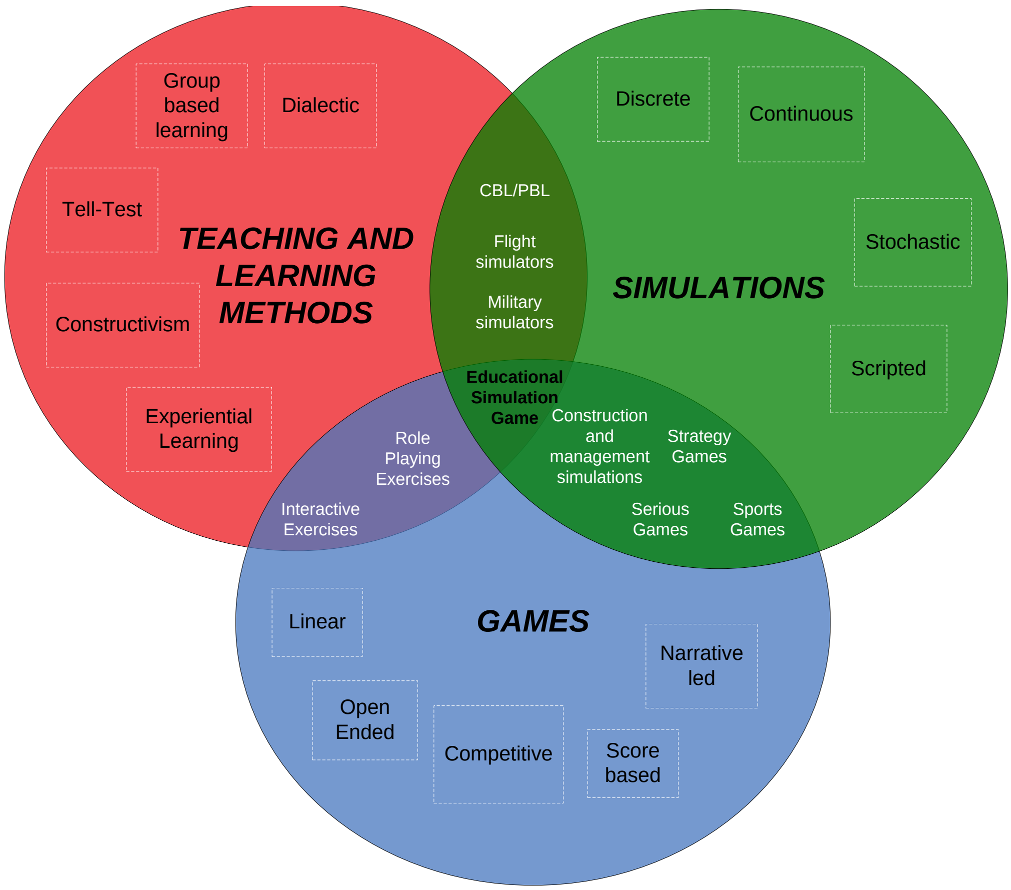


Figure 3.11 : Venn diagram showing the links between simulations, games and teaching methods and their properties

Figure 3.11 shows each of the three elements of educational simulation games, gives examples of properties or methods for each element (indicated by dashed boxes in the diagram) and shows examples of the subtypes that exist in the combination of each element. Educational simulation games are an example of experiential learning and typically follow the principles of constructivist theories of learning since they require the learner to build on their existing knowledge of a process during the simulation. Since the learner is in control of the simulation in most instances they are also a form of self-directed learning. Educational simulation games may also promote various other types of learning methods depending on their exact nature. For example, they are often played in groups rather than by individuals reducing the element of self-directed learning but introducing group based learning mechanisms including the development of teamwork and communication skills. They may also be played competitively with all learners competing against each other for limited resources in some form. This introduces elements of conflict resolution and negotiation between players which are not easily learnt through traditional teaching approaches.

In terms of the simulation aspects of educational simulation games, its verisimilitude will be compromised to balance the needs of the educational and gaming aspects of the experience. The degree of realism in the simulation may be adaptable and be matched to the learner's needs and existing ability. An educational simulation will focus on the specific elements of a system that are relevant to the learning outcomes of the teaching exercise. Aldritch (Aldritch, 2004) provides a more detailed description on the issues regarding the fidelity of the simulation in an educational simulation.

The gameplay in an educational simulation games is often the element most neglected. This is possibly due to the fact that most are designed by educators rather than games designers. Gaming aspects are often "tacked on" to increase engagement without great thought being given to the gameplay aspects of the educational simulation game. This is often true of all educational games and was highlighted by Herz (Herz, 1997) over 10 years ago, and although there have been significant improvements in the field of educational simulation games; it is still an oft-repeated criticism of such software.

3.5.4 Assessment of educational simulations and games

One of the criticisms of educational simulations and games is that they are still an unproven method for learning. There is some truth to this criticism though there are numerous examples of studies where their utility has been assessed, some of which will be referred to in this section. Educational simulations and games can be assessed from two separate viewpoints; assessment of the simulation or game itself and assessment of any learning generated by the use of the simulation or game. These two viewpoints are separate though there are linkages between them and it is latter that is of primary interest in terms of this research.

3.5.4.1 Assessing the utility of an educational simulation or game

Assessment of the simulation or game itself is generally performed through testing and feedback from users as with any evaluation of software. Initial assessment is done during the testing and evaluation of the simulation or game which should identify any bugs and gameplay or operational problems.

Feedback from actual users during operation of the simulation or game is the main method for assessing the simulation or game itself. This is generally carried out through questionnaires, interviews and feedback forms. Users are typically asked to review the game or simulation in terms of its interface design, controls, difficulty, and graphical style and also to highlight any specific problems they had in using the simulation or game.

3.5.4.2 Assessing the learning acquired through educational simulations or games

Assessing the learning acquired through simulations or games can be difficult to achieve as with any assessment of learning (see section 2.4). Specific difficulties include the problems in assessing initial levels of knowledge, differences in initial knowledge levels between students and the inherent problems in quantifying learning in some subject domains. Typical methods for assessing learning include the use of testing, questionnaires, student interviews, student feedback and analysis of game or simulation performance.

Klassen and Willoughby (Klassen & Willoughby, 2003) provide a good review of the problems encountered when assessing learning through simulation games. They describe an assessment exercise of a classroom based game, the Inventory Game, and utilised questionnaires as the method for assessing learning. These questionnaires were completed both prior and post the use of the simulation game to identify any differences in student knowledge in respect of the topic (Inventory management methods). They also tested whether repeated play of the simulation game could further improve student knowledge. Results from their work showed that simulation games can be very effective learning tools and demonstrated methods for assessing this learning.

Dumblekar (Dumblekar, 2004) provides another example in the assessment of learning from simulation games. It provides a full review of assessment issues and studies using business management games and builds upon a number of earlier studies such as that carried out by Kinnear and Klammer (Kinnear & Klammer, 1987). Dumblekar describes methods for analysing and assessing learner's responses based on structured responses to a series of factors relevant to learning. He found that smaller groups (the simulation game exercise used was a group based one) performed better than larger groups and confirmed the validity of the exercise as a learning method. He also classified the learners into two styles (Internals and Externals) and found that Externals gained more from the experience.

David Schaffer's work with simulation games for learning, or *epistemic games* as he refers to them, provides an interesting method for assessing learning. His work involves the analysis of the student's *epistemic frame* (way of knowing) through pre, post and follow-up interviews using matched pair questions. This shows a definite improvement in student learning following the use of the simulation game and that a large proportion of this learning is retained (follow up interviews carried out 3 months after the exercise). References to his work can be found in a number of sources (Schaffer, 2006a; Schaffer, 2006b; Bagley & Schaffer, 2008)

3.6 The use of games and simulations in engineering education

Engineering is applied science and as such is a highly objective and practically focussed subject. Teaching methods for engineering typically involve a combination of classroom based lectures and lab based exercises. There is typically a focus on practical coursework exercises and group based working wherever practical. Engineering knowledge is often procedural rather than declarative (though there is a great deal of declarative knowledge is be transmitted) and there is a high level of mathematical understanding required by students.

Simulation and Problem Based Learning through case studies and example projects have long being a component of engineering education. Much of the software used by student engineers involves a high degree of simulation (e.g. CFD software such as CFX, finite element packages such as ANSYS and 3D design tools such as AutoCAD). Games are not widely used in engineering education typically though a number of E-Learning packages have been utilised such as CALCrete (which teaches and tests student knowledge on concrete mixtures and structural design using concrete) and SteelCAL (teaches students about structural steel design issues).

Kolb's analysis of the learning styles for specific students by subject type (Kolb, 1984) showed that engineering students are generally of the *Converger* type and as such are strong in practical application of ideas, can focus on hypo-deductive reasoning on specific problems, unemotional and have narrow interests. They excel at abstract conceptualisation and active experimentation. As stated in chapter 2, and by Kolb himself, this does not preclude them from other learning styles (e.g. creative thinking and reflection) but is useful in highlighting their specific strengths in general terms.

Felder and Silverman (Felder & Silverman, 1998) and Betts and Liow (1993) provide a more detailed overview of the learning and teaching styles in engineering education than can be expressed here. Both papers discuss how the differences between student aptitudes for learning and traditional teaching methods can be resolved through increased use of active teaching methods and experiential learning exercises such as those offered by simulations and games. Simulation games would seem to be ideally suited to the practical nature of engineering students.

An example of an innovative teaching module for experiential learning in engineering education carried at Curtin University of Technology, Western Australia is described by Lindsay (Lindsay et al, 2008)

In particular, the topic of construction management (a standard topic within civil engineering courses) is one ideally suited to the use of simulation games for learning as it is difficult to provide students with experience of managing actual construction projects within an educational institution. It also shares much in common with other management based courses which have been shown to be well suited to the use of simulation games for learning as is evidenced with the large number of such games in use and proven to be effective.

3.7 Simulation games for construction management

Construction management combines aspects of management, and in particular project management, with engineering knowledge. Technical knowledge on engineering processes is used to plan, control and manage construction projects. The education of construction management typically combines traditional lecture based content with case studies and problem based learning exercises in order to provide students with an understanding of effective practices for managing construction projects.

Construction projects are often large, complex, expensive and risk-rich environments. It is not practical to allow students to manage actual construction projects. Although small scale replicas of construction projects can be effective, if costly, learning experiences (e.g. The Constructionarium Project)

Construction management is a practically focussed subject and simulation games have been shown to be an effective mechanism for teaching students the difficulties and issues involved. AbouRizk et al (AbouRizk et al, 1992) reviews the use of simulation of construction processes.

A number of example simulation games for teaching construction management topics will now be described.

3.7.1 Construction Management Simulation Game (CMSG)

CMSGs are typically a type of CMS that focuses more heavily on the simulation aspect than the gaming aspect. Some CMSGs are more similar to business management games, especially where they focus on contractual issues and financial management aspects of construction management. They utilised discrete-event simulation and can be deterministic or stochastic (though they often combine elements of both).

The history of Computer based CMSGs dates back to the 1960s. Nasser provides a summary of a number of these games as is shown in table 3.2.

A Comparison Chart of the Simulation Games Available for the Construction Management Field

	Game	Focus Area	Time Frame Required	Computer Implementation Needed	Limit on Number of Players/Teams	Main Construction Courses Where Applicable
1	***Construction Management Game***	*General Management skills*	*1.5hr to 1 semester*	*YES*	*Optimum 4-6 teams*	*Construction Management*
2	***Negotiation Game***	*Tradeoffs and Negotiation skill*	*1.5hr*	*NO*	*NO*	*Contract Management and Administration Courses*
3	***Parade of Trade Game***	*Effect of variability on construction productivity*	*1hr*	*YES*	*NO*	*Construction Productivity Improvement*
4	***CONSTRUCTO***	*General Management skills*	*NA*	*YES*	*NA*	*Construction Management*
5	***Super-Bid***	*Bidding skills*	*1hr*	*YES*	*NO*	*Estimating and Construction Management*
6	***Lego Game***	*Estimating and Construction Planning*	*1.5hr*	*NO*	*Optimum 4-6 teams*	*Scheduling, Company Management*
7	***Road Building Negotiation Game***	*Group Negotiation and planning*	*1hr*	*NO*	*Optimum 4-6 teams*	*Construction Management*
8	***Equipment Replacement Game***	*Equipment and resource management with market demand*	*1.5hr to 1 semester*	*Yes*	*Optimum 4 teams*	*Construction and Company Management*
9	***The Marketing Game***	*Construction Marketing, Company management.*	*1hr*	*Yes*	*4*	*Introduction to construction, Marketing Courses*

Table 3.2: A comparison of various CMSGs (taken from Nasser, 2003)

A number of specific examples of CMSGs will now be described in more depth to illustrate this topic in more depth.

3.7.1.1 CONSTRUCTO

This early example of a CMSG was developed by Halpin in the early 1970s (Halpin, 1973; Halpin, 1976). It simulates a construction project based on an activity network (using the CYCLONE modelling language developed by Halpin) and seeks to teach players about the effects of weather and labour productivity on the construction process.

Players assign work crews and activities each turn of the simulation and attempt to complete the project successfully and profitably. CONSTRUCTO is one of the most commonly cited CMSGs and was found to be an effective learning tool.

3.7.1.2 Parade of Trades

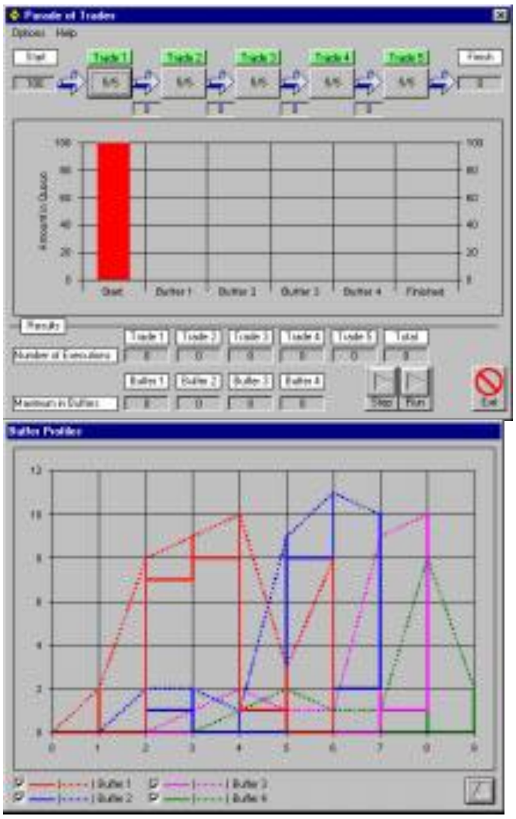


Figure 3.12 : Screenshots from the computer version of the Parade of Trades simulation game and graph of results taken from (Choo & Tommelein, 1999)

The Parade of Trades game was developed by Tommelein and Choo (Choo & Tommelein, 1999; Tommelein et al, 1999) and is aimed at simulating a construction process with particular focus on repetitive linear jobs. The purpose of this game is to demonstrate the impact variability and dependence have in a construction environment where multiple trades follow each other in a linear sequence and work output by one trade is handed off to the next trade. Images related to the game are shown in Figure 3.12.

3.7.1.3 The Equipment Replacement (ER) Game

The ER game was developed by Nasser (Nasser, 2002; Nasser, 2001) and is concerned with teaching students about financial management issues using the replacement of construction equipment as the simulated scenario. It is a multiplayer game and requires students to develop appropriate strategies for buying and selling equipment in order to maximise their finances.

The game was run with students in four teams, with 2-4 students in each team. Players were tasked with selecting excavation equipment to match a simulated demand. They were allowed up to a maximum number of equipment which was of categorised into three types. The simulation was advanced in quarterly periods over a defined period and at each step players must decide whether to purchase additional equipment or sell the equipment they possess. Equipment degrades in productivity and reliability over time and the task is to manage their fleet of excavation equipment in order to fulfil demand and maximise profitability.

Results from the exercise showed that students found the ER Game to be a useful learning exercise though they did not find it very realistic. Nasser identified that those teams that worked most effectively as a team and had strong leaders performed best. However, the low number of students in the study means that the any results are not statistically significant.

A screenshot of the ER game is shown in Figure 3.13.

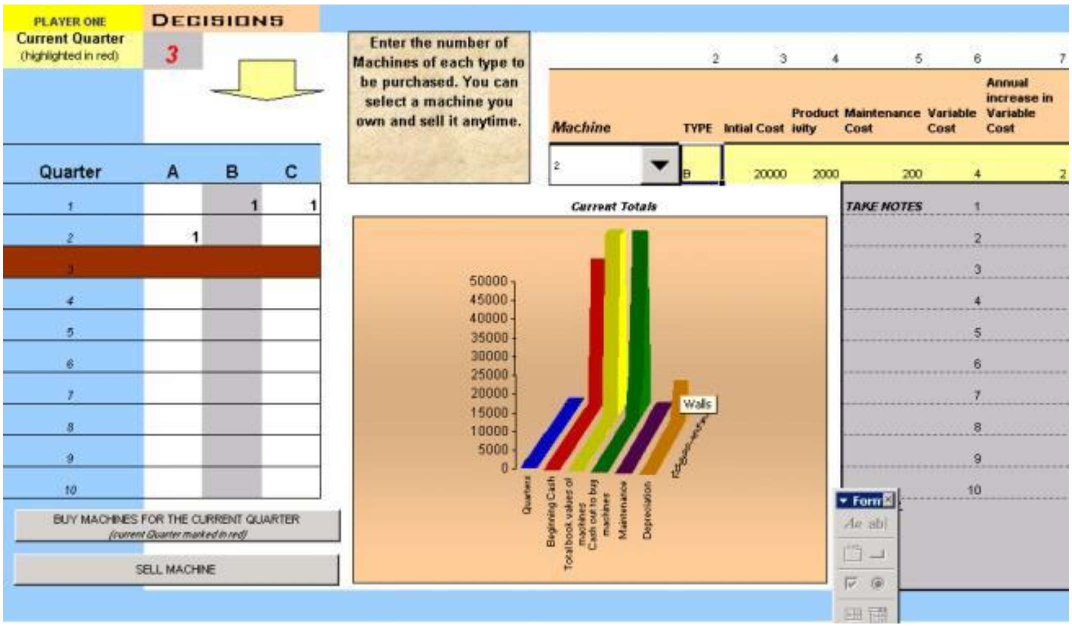
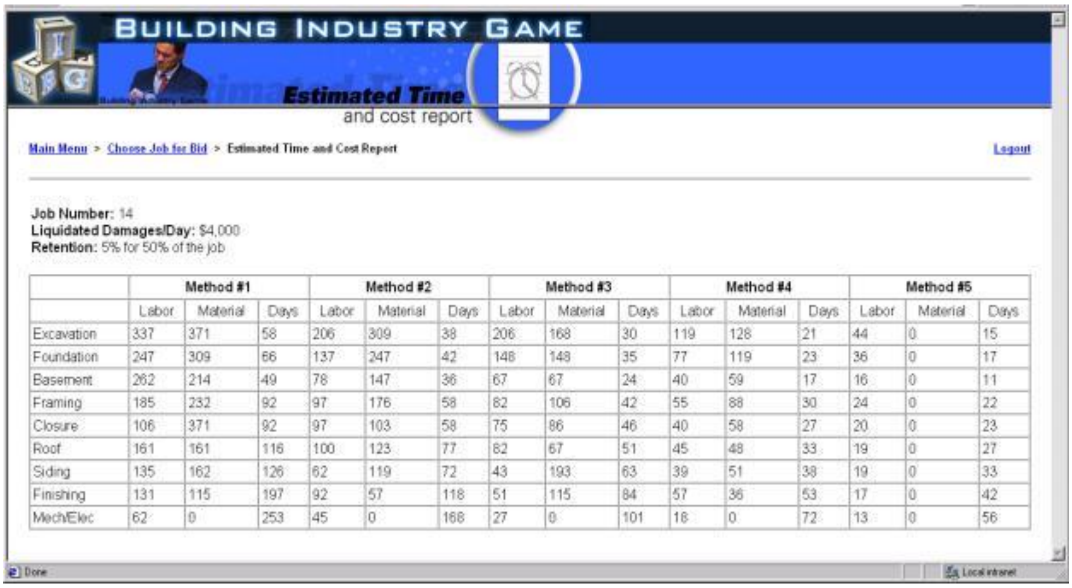


Figure 3.13: An example screenshot from the ER Game (taken from Nasser, 2001)

3.7.1.4 The B.I.G Game

The Building Industry Game (Johnson et al, 2003) is a simulation of running a construction company. Players bid for construction projects and manage their resources in order to complete construction work. It fouses on the financial management aspects of construction management. Simluated projects are offered for tender each simulated period of differing values, durations, complexities and sizes. Players choose projects to bid for and input bids based on the information provided. The game is a competitive multiplayer game where each team is competing for work. There is also a computer player who bids on projects. Each project is made up of a number of activities and the player can select from a number of methods to complete each job. The choice of method affects the cost (in terms of labour and materials) and duration of each job.

Players can view a variety of reports and also look at the state of projects in progress. Figure 3.14 shows the job information screen for a project with the choice of methods for completion and the associated information for each method.



	Method #1			Method #2			Method #3			Method #4			Method #5		
	Labor	Material	Days	Labor	Material	Days	Labor	Material	Days	Labor	Material	Days	Labor	Material	Days
Excavation	337	371	58	206	309	38	206	168	30	119	128	21	44	0	15
Foundation	247	309	66	137	247	42	148	148	35	77	119	23	36	0	17
Basement	262	214	49	78	147	36	67	67	24	40	59	17	16	0	11
Framing	185	232	92	97	176	58	82	106	42	55	88	30	24	0	22
Closure	106	371	92	97	103	58	75	86	46	40	58	27	20	0	23
Roof	161	161	116	100	123	77	82	67	51	45	48	33	19	0	27
Siding	135	162	126	62	119	72	43	193	63	39	51	38	19	0	33
Finishing	131	115	197	92	57	118	51	115	84	57	36	53	17	0	42
Mech/Elec	62	0	253	45	0	168	27	0	101	18	0	72	13	0	56

Figure 3.14 : Screenshot from the B.I.G. game (taken from Johnson et al, 2003)

A number of external factors affect a player's productivity such as weather, change orders, the cost of materials and labour availability.

Student strategies and behaviour patterns show that they have experience difficulty in managing the simulation and can become frustrated with their performance. The authors propose changes to the simulation settings to reduce this difficulty. No significant results are reported in the available literature.

3.7.1.5 The MERIT Game

Developed at Loughborough University in the UK, the MERIT (Management, Enterprise, Risk, Innovation and Teamwork) Game (Wall & Ahmed, 2008) involves teams of players in the management of a fictional construction company and tasked with developing and planning long term strategies for the company's success.

Team members take individual roles within the simulation and make decisions on a number of factors including resource levels, project bids and marketing strategies. Team decisions are input and (can be done via email for distance learning operation) and the simulation is advanced and results are calculated. Players can view their company's performance through variable measures and then make appropriate management decisions on reflection of their performance. Teams also receive feedback from the game controller (a member of teaching staff) on their performance each simulation period (typically quarterly intervals).

Feedback from players was obtained through a short questionnaire and results from the exercise showed that students found the experience to be both useful and informative and appreciated the feedback from the Game Controller on their performance. Figure 3.15 shows a screenshot from the game.

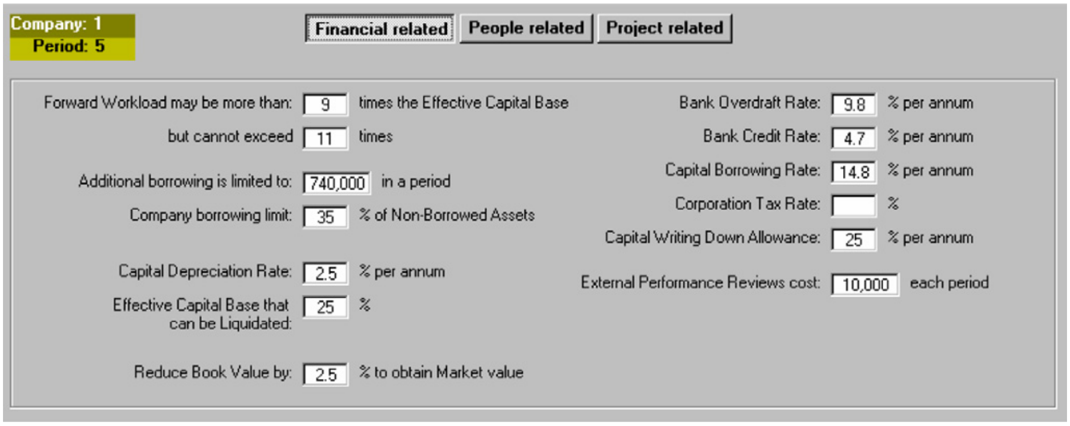


Figure 3.15 : Screenshot showing financial settings in the MERIT game (taken from Wall & Ahmed, 2008)

3.8 Observations on simulation and gaming and its utility in engineering education

This chapter has reviewed the fields of simulation and gaming and more specifically their role within an educational context. Types and examples of simulations and games were provided along with a description of simulation games which combine aspects of both.

The role of simulations, games and simulation games in an educational setting were described with examples and discussion of the issues in balancing learning, gaming and simulation aspects. Assessment of simulation games and learning arising from them was described.

Engineering education was discussed along with examples of typical teaching methods and learning styles for engineering students. This confirmed the potential for simulation games in engineering education. The study of construction management within civil engineering education was highlighted as an area where simulation games could provide learning benefits. A number of case studies of successful simulation games aimed at construction management teaching were described.

4. Initial experiments in simulation game design

This chapter describes work done by entirely by the author as part of this research programme. It involves the design and development two new educational simulation games. The games, their aims and objectives, and the developmental process are described. The work detailed in this chapter was a key element of the research programme. Lessons learnt during the development of these two games was essential in extending and developing the Muck and Canal games described in chapter 5.

The first game described here, *BizSim*, was developed to simulate the business plans of students as a novel and innovative coursework on a teaching module. The module and results from this work are outlined in chapter 6. BizSim is able to model almost any business model (within some constraints) which makes it particularly interesting since most simulation games of its type focus exclusively on a single simulated scenario.

The second game, *SubCon*, was the initial attempt at producing a simulation game for teaching aspects of construction management processes. The generic modelling capability of *BizSim* was incorporated into SubCon so that it could be used for a wide variety of project scenarios. The SubCon game is a single and multiplayer game. It aims to teach students about the issues involved in managing a project employing a range of semi-autonomous subcontractors from the viewpoint of the main contractor and a subcontractor. The SubCon game was not used in teaching but an initial experimental trial of the game was carried out and is described in chapter 7.

Both the BizSim and SubCon simulation games were written in the Borland Delphi® programming environment and run on any PC running Microsoft Windows.

4.1 BizSim - A simulation game used to simulate student business enterprises

BizSim is the name used to describe a simulation game developed to form a major part of a teaching module at the University of Nottingham. The simulation game aims to provide students with a simulated experience of running a Small or Medium Enterprise (SME) focussed on delivering a single product or service. The novel feature of BizSim is its ability to simulate a wide range of products or services so that it can be used to model business plans generated by students.

The teaching module using BizSim, *Science, Technology and Business (STaB)/Management for Positioning Technologies (MPT)* was an optional module for postgraduate students on a Masters course run by the Institute of Engineering Surveying and Space Geodesy (IESSG) at the University of Nottingham. Details of the module are given in the chapter 6.

4.1.1 History and background

BizSim was developed in order to simulate the business plans developed by students on the STaB module. The intention was to provide the students with a chance to examine the practical implications of the business planning exercise that formed a major part of the module.

In the initial year of running the STaB module, a commercial business simulation, SESAMEE (http://www.theorangegroup.com/sesamee.html) was used. This provided the student's with some experience of the issues involved in running a Small to Medium business Enterprise (SME) but lacked engagement with the students as they had no prior knowledge or development of the business. It required the student to learn about the business (gas detection equipment) and market being simulated which was an additional overhead on the students which was not ideal in terms of the teaching module requirements and student time availability.

For the following years of the module's operation BizSim was used to simulate the students own business plans. The STaB module was redesigned as the MPT module in the 3rd year of operation (see chapter 6 for further details) and the use of BizSim continued to be a key component of the teaching module.

From the viewpoint of the research described in this thesis, it represented an initial opportunity to create a simulation game to examine the utility of management type games as a pedagogic device. The requirement to produce a simulation that could model a vast array of business models was an innovative and challenging aspect of the work. The fact that this was preceded by the use of commercial management simulation game provided an opportunity to examine the impact on teaching of using bespoke versus commercially available simulation software.

A significant constraint on the use of the BizSim simulation game was the very short time available for modelling the student business plans. This was necessary due to the scheduling of the teaching module, which is further explained in chapter 6, and meant that the process of generating the simulation models was an area of the BizSim that received considerable developmental time and focus during the games development.

4.1.2 Description of the Simulation Game

BizSim consists of two main elements; the Creator tool and the Simulation Game itself. Both these elements draw on a common data model that represents the simulated business environment. The creator tool is used to generate bespoke simulation environments to reflect the start-up companies proposed by the student business plans and the business environment in which they will operate. Once the simulations have been created and tested they are ready to be used by the students.

4.1.2.1 The Simulation Model

The data model used by BizSim was developed through extensive research of similar simulations and games in the domain of business management simulation and management flight simulators as described by Sterman (Sterman; 1992). Examples of games in this area were mentioned in chapter 3 and include *The Marketing Game* (Tonks & Armitage, 1997), MAGNUS on-line (Yeo & Wang, 2006) along with the SESAMEE simulation used in the initial year of the STaB teaching module.

The generic nature of the simulation model was the primary constraint on the underlying simulation model. The entities, their properties and relationships between them were defined in sufficient detail ensure that all possible businesses developed by the students could be simulated. This meant that the model had to be able to represent both a product or service based industry. It also had to be able to represent a range of potential markets.

A key aspect of the simulation model is the concept of the *Market*. Each simulation model defines a specific market for the simulated start-up SME. These are based on a set of archetypes and are highly customisable. The market acts as the environment in which the simulated business operates. Each market has a number of properties as shown in Table 4.1. The values of these properties, in conjunction with the properties of the simulated business, determine the results of each step of the simulation. The student or player has little ability to make changes to the market directly. The market will change in accordance with its own properties, such as growth rate, or due to stochastic variations triggered within the logic of the simulation game as events. As these events can be partially determined according to player actions there is an indirect method for the player to influence the properties of the market, though they are not explicitly aware of this relationship.

Selected properties for two of the main entities in the simulation model are shown in Table 4.1. This provides an indication of the complexity and content of the simulation model but does not include all the properties of the entities.

The simulation model is based on a number of fundamental concepts and takes a functional approach to modelling a business focusing on the key elements. Some complex relationships given in other similar simulations are deliberately omitted in order to ensure the generic nature of the model.

Entity	Property	Description
Market	*mktID*	The unique identifier for the market entity used to identify the market within the simulation model
	mktType	The type of market represented by an enumerated type. Examples include Luxury, Specialist, Disposable or Other.
	mktGrowth	The annual percentage growth rate for the market
	mktDesc	A short text based description of the market for UI selection purposes primarily
	mktSize	The size of the market in annual sales
	mktInfluence	A modifier for the influence of marketing spend on this market to customise beyond the *mktType*
	mktVariability	Percentage variability of the market. Adds an element of randomness to the market over time. Can be used in conjunction with *mktType*
	mktVolume	Enumerated type in format Low/Medium/High used to classify the sales volume of the market
	mktPrice	Enumerated type in format Low/Medium/High used to represent the type of price values found in this market. Further classifies the market in conjunction with *mktType* and *mktVolume*.
Company	*coName*	Name of the business being simulated for display purposes and as the identifier for the company data
	coPrSv	List of products or services offered by the company. Defined to allow up to 10 products or services but restricted in code to a single product or service.
	coCash	Current cash level for the company
	coTech, coAdmin, coSales, coManage	Number of staff in each of the four categories of staff type in the simulation
	coMktSpend	The amount of monthly marketing spend by the company in total

Table 4.1 : BizSim Simulation Model – Properties of key entities

For example, both SESAMEE and The Marketing Game (Tonks & Armitage, 1997) use a more complex model of marketing for their simulations where the player can specify in detail the types of marketing campaign they wish to employ and the effects on different marketing strategies are simulated. This is suitable in a simulation focusing on a predefined company and in a heavily scripted simulation based on actual data from similar business environments. It is not appropriate for BizSim. Its generic modelling of business environments would make such an approach inappropriate. It would also be very difficult to define such complex relationships in the short period that was available for creating the simulations from the student business plans (typically 3-5 days).

The design of the BizSim simulation model is focused on its ability to simulate a wide range of business environments. In order to achieve this aim, clarity and simplicity are essential. This is not to limit the ability of the simulation to model complex environments but to ensure that all potential environments can be modelled. Complexity is modelled in the interaction between the key entities of the model and by the scripting of dynamic changes to the underlying model during the simulation. As the player advances the simulation, the model updates the various entities within the model in accordance with the current market conditions calculated by the simulation from the tutor’s original settings and the properties of the company, including its product(s) or service(s), as defined by the player during gameplay.

4.1.2.2 The BizSim Creator Tool

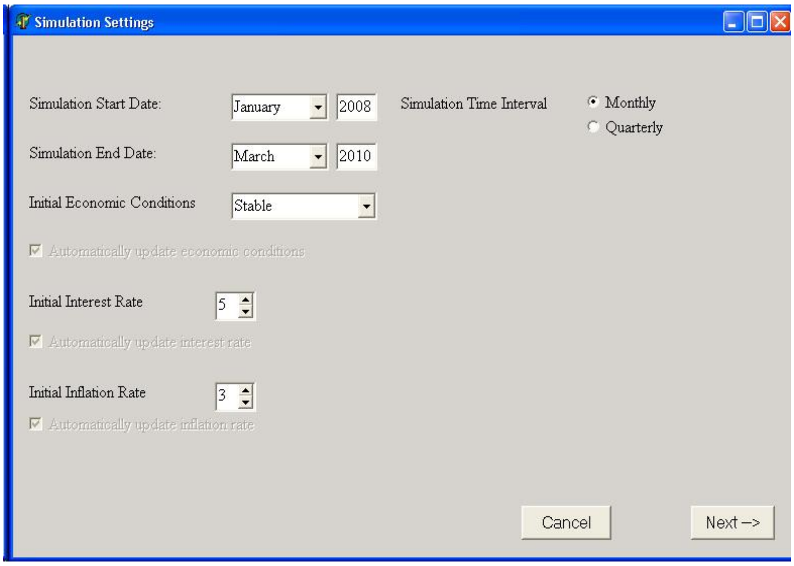


Figure 4.1 : BizSim Creator – General simulation settings

As stated in section 4.1, the generation of unique simulations based on student business plans is the primary aim of the BizSim simulation game. In order to achieve this aim, a software tool was designed and developed. The *BizSim creator* is a simple user interface to be used by the tutor which generates and initialises the simulation model based on the students’ business plans. Examples of the BizSim creator User Interface are shown in figures 4.1-4.4.

The BizSim creator was designed as a series of forms-based interface screens. Each screen represents an entity within the simulation model and contains all the key properties for that entity. Optionally, detailed and complex properties can be set if necessary, or left to the default values. Figure 4.4 illustrates one of these more complex functions to model markets within the simulation.

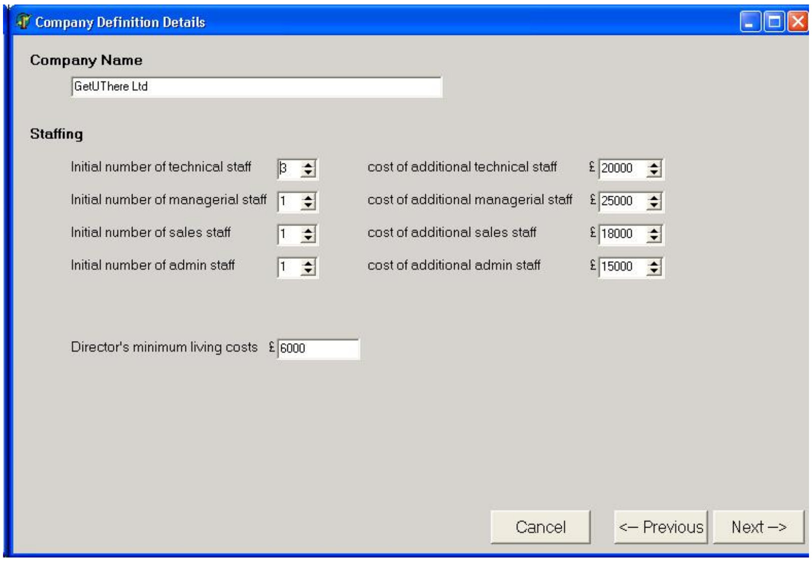


Figure 4.2 BizSim Creator – Company settings 1

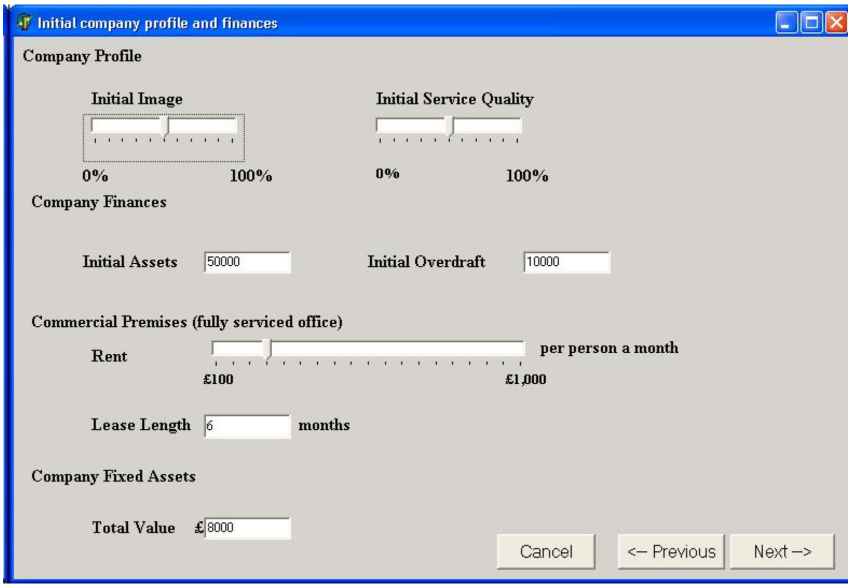


Figure 4.3: BizSim Creator - Company settings 2

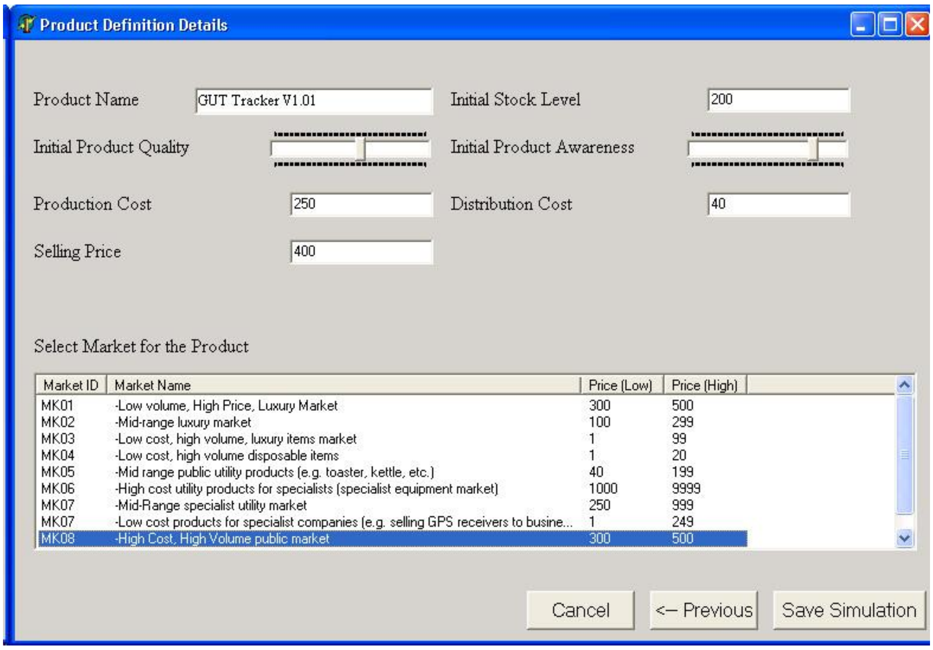


Figure 4.4: BizSim Creator – Product details and market selection

4.1.2.3 The Simulation Game

The BizSim simulation game itself acts as an interface to the simulation model for the player. It controls the operation of the simulation model allowing the player to advance the simulation and view the results of their actions. It consists of a small number of form based interfaces that display information on the simulated company; its resources, products or services, financial records and general information on the current state on the simulated environment.

Figure 4.5 shows the main interface to the simulation game controlling access to the various interface elements and enabling the advancement of the simulation. It also displays key company information and recent events and allows the player to exit the simulation. This is also the entry point to the simulation upon running the game.

Figure 4.5 BizSim – Main interface

There is no way for the player to reverse or undo a simulation step. It is also not possible for the player to exit the simulation without any changes made to the simulation environment being saved. The text window on the lower right of the UI lists recent events as they occur. These are triggered stochastically.

Initially, events could occur at any time during the simulation. During testing it was discovered that this could lead to events being triggered too often. As a result, the simulation was altered to ensure that events could only be triggered once in every 3 steps of the simulation (1 event every 3 months under the default simulation settings). The change was made for teaching purposes to ensure that players had time to reflect on each event and make appropriate decisions without being overwhelmed by new events.

Figure 4.6 shows the part of the simulation game where the player can view and edit those properties relating to the company and its key resources. These include staffing, marketing and workplace information. Staff are broken into 4 types; Administrative, Technical, Sales and Management. Each type of staff will have an impact on the company's performance affecting sales, quality and the image of the company and its product(s) and/or service(s).

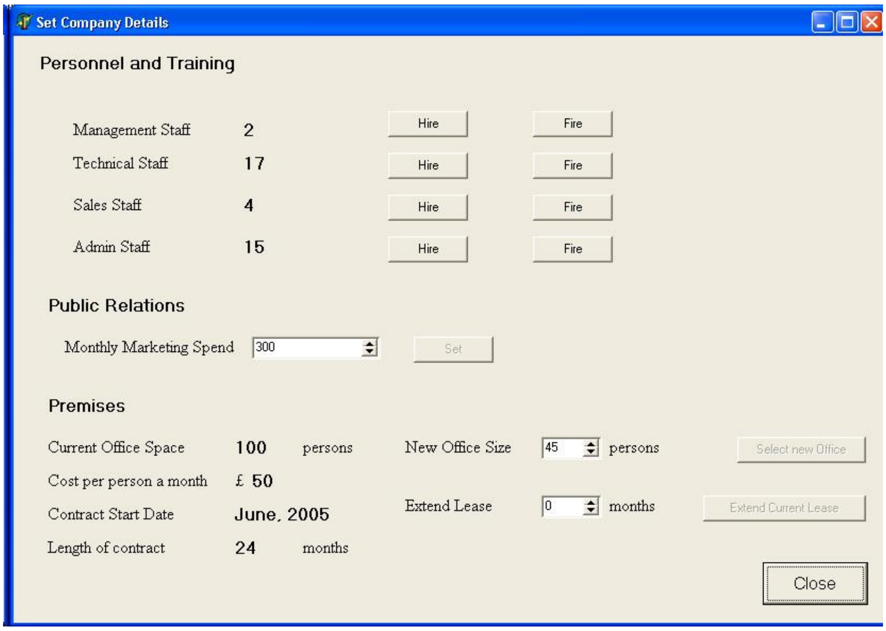


Figure 4.6 BizSim – Company Information

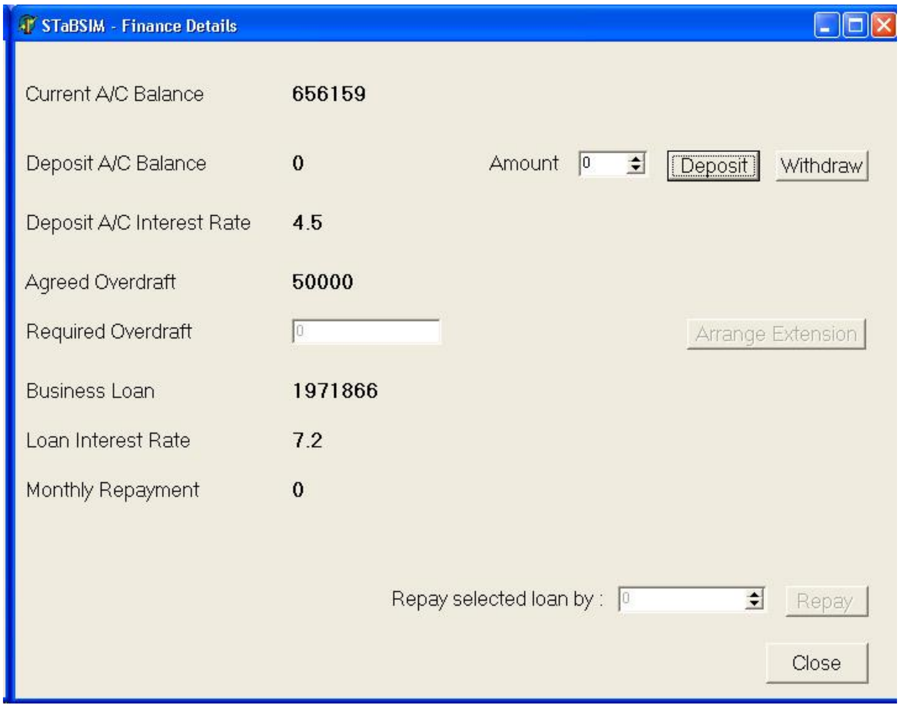


Figure 4.7 BizSim – Financial Interface

Financial options are tightly constrained in the game to ease its capability to model a vast range of business models. The financial interface of BizSim (Figure 4.7) allows the player to view the current financial status of their company and enables them to place any surplus cash into a deposit account thereby gaining interest, though reducing their liquidity (there is a delay of 3 months on accessing cash in the deposit account). Details of any current overdraft are also shown here. It was originally planned for the player to request additional loans here and enforce a tight overdraft limit. Testing of the game led to a decision to simplify these elements and simply allow the player to have a single overall business loan and repayment scheme as defined in their business plan and to have an unlimited overdraft facility.

The unlimited overdraft facility ensures that the player is able to complete the game to the end of the specified simulation duration (24 months by default) irrespective of how poorly their company performs financially. Though unrealistic in both simulation and gaming terms, it is essential for delivering the learning outcomes of the exercise to every student.

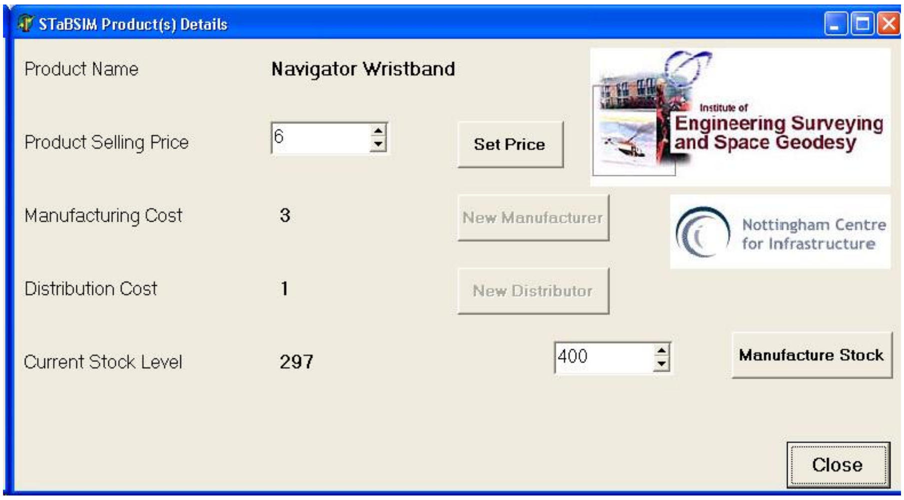


Figure 4.8 BizSim – Products and Services Interface

Figure 4.8 shows the area of the game where players can make alterations to those settings pertaining to the product or service being offered by their simulated business. BizSim was designed to allow multiple products or services per company (as shown in Table 4.1) but initial testing of running the game concluded that it was best to limit each player to a single product or service during the simulation. This allows the student to focus on the key aspects of the exercise from a learning perspective. It also represents the most likely scenario for a small high tech start-up company in its first two years.

A critical component of BizSim (or any other simulation game) is the feedback on progress given to the player. Figure 4.9 shows the reports and charts page of BizSim that provides the primary arena for the player to view his performance to date. A number of pre-defined reports and charts can be selected from the drop down list and displayed in the report and chart windows that make up the interface. These include monthly financial statements, profit and loss accounts, monthly sales charts, cashflow charts and market share graphs amongst others.

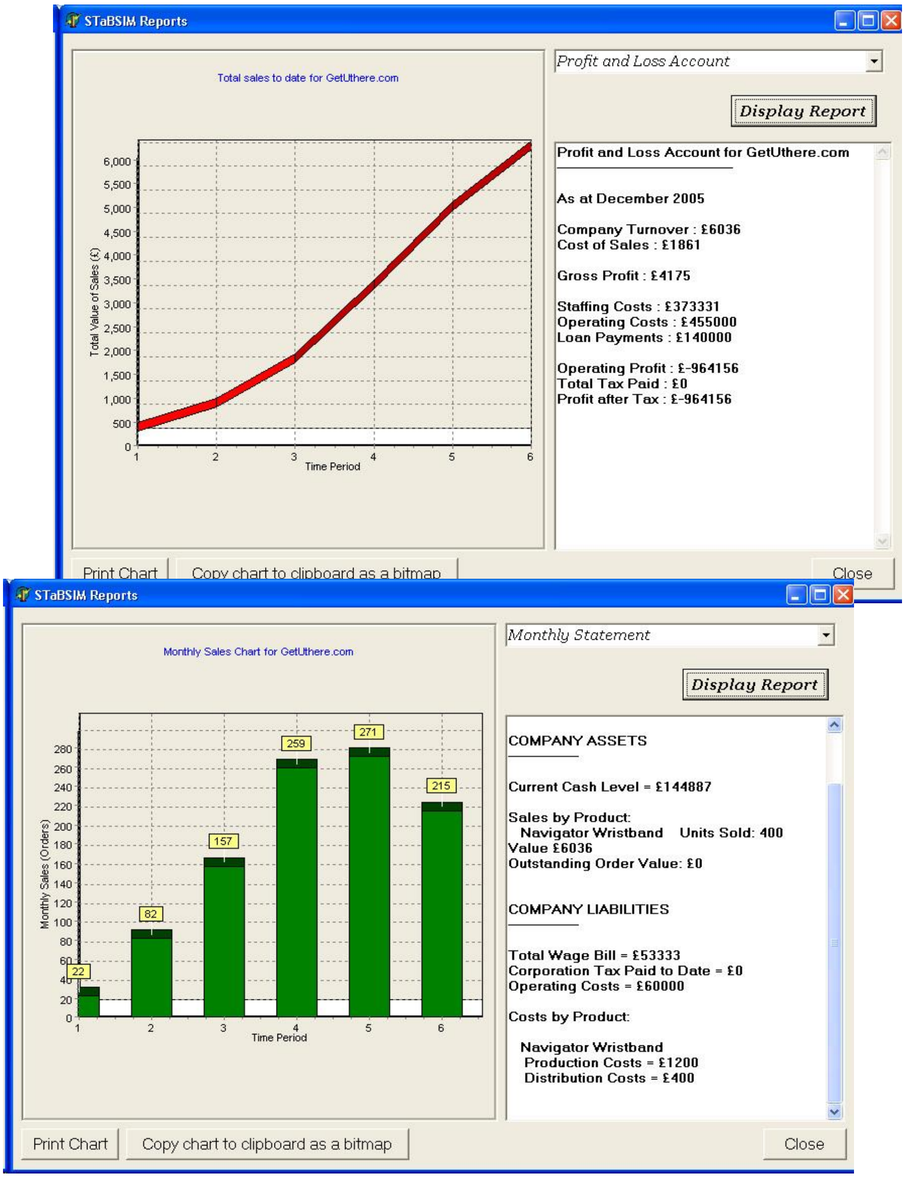


Figure 4.9 BizSim – Company reports and charting examples

4.1.3 Key Features and Limitations

Many of the following issues have been previously raised but this section is intended to both highlight and summarise the main features and limitations of BizSim. Each is briefly described and discussed in relation to the aims of the research programme. Key features of the BizSim simulation game:

1. Generic modelling and simulation – The ability to model any company devised by the students and simulate the early years of operating the company has been the primary focus of the development and design of BizSim. In order to achieve this some limitations were imposed but these were deemed a worthwhile trade off in order to be able to produce bespoke simulations to order.

2. Simulating actual student business plan – There are huge potential gains in student engagement and immersion by utilising their own business plans in the simulation. It ensures the student's knowledge of the content of the simulation is high and is an essential part of the overall learning outcomes for the teaching module of which BizSim forms a key part.
3. Tutor defined stochastic events – The ability to design and include events based on the content of student business plans enables the tutor to test the student's ability to manage the business in reaction to specific issues whilst maintaining the realism of the simulation. Their stochastic nature ensures that the simulation does not follow a scripted pattern and requires each student to devise their own management response.
4. Simple easy to use interface – Since the module employing the game would require students to run the simulation unsupervised, potentially outside of the confines of the university environment and during vacation times it was essential that the game was easy to use and the interface employed was intuitive. Experience using the SESAMEE software in the initial year of the teaching module showed that many students struggled with the complexities of the interface. It was important to ensure that BizSim was user friendly. This was assessed through in-game feedback mechanisms during its operation and students provided positive feedback in regard to this (section 6.3.4).

It is important to highlight the limitations of the BizSim software in order that these are taken into account when analysing results from using the games with students. The main limitations and the effects of or reasons for each are given below:

1. Simplified business model – The simulation has been simplified in comparison to other simulations that focus on a single pre-defined business and market. This is an unavoidable side effect of its key requirement for generic business modelling.
2. Compressed modelling timescale – Limitations of the teaching schedule in which BizSim was employed meant that there was a very short period between receiving the students' business plans and producing the simulation based on each plan. This inevitably reduced the ability to develop the simulated businesses to their full potential.
3. Single product or service only – A product of limitations (1) and (2) but worthy of individual mention, BizSim has been limited to a single product or service per company though the underlying data model was developed to enable multiple products or services to be easily added at a later date if required.

4. Restrictive staffing model – The game was developed to include the four main types of staff; administrative, technical, sales and management. Each staff type has a number of key properties attached to it such as workload and skill. It does not however, differentiate between the individual properties of each staff member. This is not that unusual within the field of business management simulations and would have proved difficult to achieve given limitation (2).
5. Simplified marketing simulation – The role of marketing within the business environment has been simplified to consist of a total marketing spend by the company rather than differentiating between the specific types of marketing (e.g. direct marketing, telemarketing, TV or radio advertising) that find be found in other business simulations. This was deemed necessary due to limitations (1) and (2).

4.1.4 Extensions and Modifications

BizSim was subject to ongoing development and revisions over the lifespan of the STaB and the MPT modules. These ranged from changes instigated from student feedback, analysis of student data and in relation to modifications and extensions to the underlying simulation data model.

Each year's student intake produced a range of business models, products and services. With a single exception (section 6.3.2), all were modelled using the simulation. The varied range of business plans and models lead to a number of extensions to the underlying data model in order to improve the simulation for future students. Modifications and additions were also made to the simulation game in light of findings from use of the software and feedback from students (see section 6.3).

An example of this would be the addition of specific reports and charts between the first and second year of using BizSim based on feedback from the students. The introduction of outstanding and delayed payments from customers was also modified and expanded during operation to introduce an additional element of uncertainty and risk for the students to understand and manage. This also improved the verisimilitude of the simulation.

4.2 SubCon – A simulation game for teaching concepts of subcontracting in the construction industry

Arising from the successful development and use of the BizSim simulation game described in the previous section, it was decided to develop a simulation game for teaching issues more specifically concerned with engineering and in particular regard to the subject area of construction management.

Issues related to the teaching of construction management along with descriptions of the various key aspects of the subject domain were described in chapter 3 (section 3.7). It was decided to focus attention on the problems and opportunities afforded by the use of subcontracting within construction as this was identified as an area where student knowledge is often lacking and where the use of simulations and games may be a highly effective teaching method. Tommelein (Tommelein et al; 1999) makes these points clearly in her work developing the *Parade of Trades* game described in chapter 3 (Choo & Tommelein, 1999; Tommelein et al, 1999) and that game was one of the primary inspirations for the work now described. The *LEAPCON* game (Sacks et al, 2007) provides a more recent example of similar work examining the impact of a sequence of activities on construction productivity, although it focuses on Lean Construction practices.

4.2.1 History and background

The SubCon game is concerned with the use of subcontracting within the construction industry. It aims to provide the player with understanding of the issues and complexities associated with this practice. The game has been developed to the prototype stage and has been tested with postgraduate students taking the roles of players in the game.

4.2.2 Description of the Simulation Game

The SubCon simulation game is intended to demonstrate the effects of subcontracting on a construction project. An early decision during the simulation game's development was to allow the actual construction project simulated to be user definable. It was determined that the best approach to achieve this aim was use a simulation model based on a standard project activity network with suitable adaptations to meet the requirements of the SubCon simulation game.

Activity networks are commonly used technique for modelling projects and are widely used in the management of civil engineering projects. This approach to modelling projects has been widely used in many CMSGs (for example, CONSTRUCTO (Halpin, 1976; Halpin, 1973))

The SubCon game was initially intended as a single player game with the student taking the role of the main contractor. During the design phase, another possible mode of play was identified and it was decided to develop the game such that both options could be evaluated. The multiplayer mode of play was identified late in the development phase and therefore utilised the same interface as the single player game. The actual multiplayer collaboration and negotiation aspects of the game were performed through dialogue and on paper. The results of this exercise, mainly resource and finance allocations, were then input to the simulation game manually.

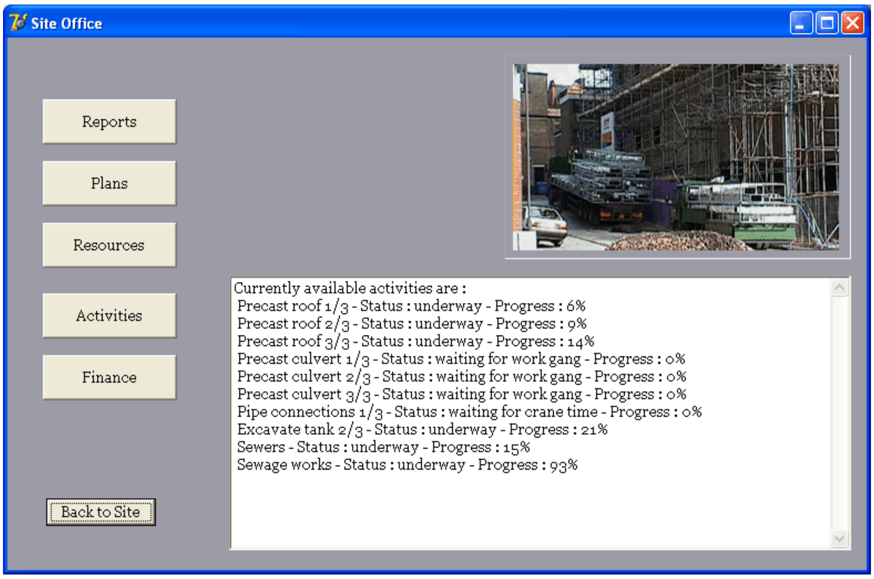


Figure 4.10: SubCon game screenshot showing current activity progress

Figure 4.10 shows the main site office screen which provides the interface to main areas of the game (project finance, reporting, resources, planning and activities) and shows current activities and their progress.

A screenshot showing project reports is shown in Figure 4.11. The report shown is the current project bar chart. Completed activities are shown in green, those awaiting resources in amber and those awaiting completion of other activities in red.

The initial trials with postgraduate students playing as a group of contractors identified a number of areas for improving the game and were useful in examining contractor behaviour for further development of the Game AI (section 3.3.1) when running in single player mode. Each student was given a role or role(s) to play within the game and given a brief of the requirements of each role to use. For example, a subcontractor may want to maximise their profit on the project or to limit their time on site as much as possible.

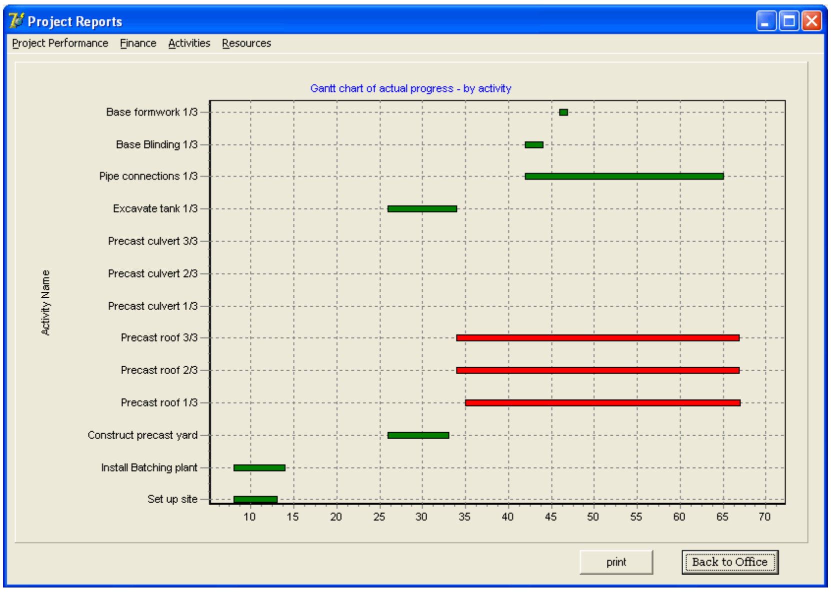


Figure 4.11: SubCon game – project bar chart showing current progress

4.2.3 Key Features and Limitations

Key features of the SubCon game are as follows:

- Highly Flexible – The game can be used to model any construction project that can be modelled using an activity network structure. This is a key feature of the game as it enables the game to be utilised across a vast range of project types easily.
- Multiple Roles – The game can be run in a number of modes to enable a group of players to take the part of each contractor within a project or a single player to take the role of a main contractor and the game take the subcontractor roles.
- Customisable – Specific parameters of individual activities can be altered to reflect differences in the complexity of similar tasks. Resource parameters can also be customised to simulate differences in performance across a range of work types.

Limitations of the SubCon game as described:

- It can only model construction projects which can be represented by an activity network
- Each activity can only have a single working resource attached to it (although other resource requirements can be linked to the resource such as craneage)
- The level of interaction and control afforded to the player is low in relation to a typical simulation game.

- The user interface is functional but does not offer the detail and specific control options found in some other construction management simulation games (e.g. The B.I.G game (chapter 3) and the Muck Game (see chapter 5)). This limitation was deemed necessary to enable SubCon to be able to model such a wide variety of construction projects

4.2.4 Extensions and Modifications

SubCon was modified during the initial trial described in 7.2. Feedback from running the simulation game with researchers was an important component of the games development and was used for updating the game. Some updates were deemed of sufficient urgency and value to be included during the trials. An example of this would be the addition of functionality to make discretionary payments to subcontractors for the main contractor. Other modifications were noted and recorded for later development work such as the ability for contractors to allocate individual resources to gangs manually (SubCon as described in section 7.2 had the work-gangs predefined and fixed in the data model).

As previously described, it was also extended from its original specification during the development phase to enable the game to be run by a single player or as a multiplayer game.

4.3 Conclusions and summary on the development of new simulation games for learning

Both the opportunities and challenges in developing simulation games for learning have been illustrated in the two games described in this chapter. In particular, the balancing of gaming, simulation and teaching components was a complex issue to resolve. Important lessons were learnt in this area which provided some practical experience to back up the research findings in this area outlined in chapter 3.

Both the educational simulation games outlined were designed to be capable of modelling a wide range of simulated scenarios. This provides great adaptability and enables the games to be reused in a variety of scenarios thereby increasing their educational potential. For the BizSim game, generic modelling was the primary requirement of the software in its educational role. The successful implementation and testing of this (see chapter 6) led to the decision to include it in the SubCon game. This was achieved through the use of extended activity networks to model construction projects.

In developing educational simulation games capable of simulating a wide variety of scenarios, design compromises were required. For example, BizSim was restricted to companies providing a single product or service during development, though the capability to produce multiple products or services is included in the underlying data model. And SubCon can only model those engineering projects that can be represented using activity networks.

The developmental process for both the educational simulation games described in this chapter was a critical component of the overall research programme and a great number of lessons were learnt for the major developmental work described in chapter 5. BizSim was used in four years of teaching and was shown from feedback and assessment to be a highly useful tool for improving student learning (see chapter 6). Many of the developmental and design challenges overcome in the creation of the SubCon game were transferable to the development and creation of the Muck and Canal games described in chapter 5.

5. Simulation games for engineering education and the tools to manage and monitor their use

A simulation game for teaching aspects of project management, and in particular planning and control, to students had been in existence for some time at the University of Nottingham. This simulation game, referred to as the Muck or Dam Game, had been used in a number of small teaching trials which are described in chapter 7. It was decided that the Muck game could be used to investigate the research aims of this thesis successfully. However, the simulation game would need a great deal of modification and extension in order for it to be suitable for the types of experimental work needed for this research.

This chapter describes the development work undertaken extending and modifying the Muck game in order to produce a simulation game that would be able to be used in achieving the outcomes of this research work. It also describes the development of a new simulation game based on the Muck game, the Canal game and the design and development of a software utility, *the Muck and Canal Game Umpire* (MCG Umpire), that would manage the operation of both games for teaching purposes. It would also perform tracking and monitoring of student activity in both games, an essential requirement for the purposes of the experimental work to be carried out (described in chapters 8-10).

The Canal game is a game in its own right but could also be said to be a variant of the Muck game as it employs a similar interface and models a similar type of construction process. The Canal game was developed to test the hypothesis that learning occurring through the use of simulation games would be transferable and thereby answering the 6th objective of the research as outlined in section 1.2. The Canal project scenario was designed to be non-linear and of a much different scale to the Muck game whilst following the same fundamental principles.

5.1 Muck Game

5.1.1 History and Background

The Muck Game was not written originally for this research, and it is therefore felt necessary to include a brief history to enable readers to place it in context of construction management teaching. The following description was developed from conversations with three people who were instrumental in the early development – Dr M J Mawdesley (University of Nottingham, UK), Dr S Al-Jibouri (Twente University, Netherlands and Prof D Scott (Curtin University of Technology, Perth, Australia)

The game was originally written in the early 1970s as a student project in the Department of Civil Engineering at the University of Nottingham. The work was done by Andrew Rose under the supervision of Dr D McKay. There were no related publications and the only documentation was in an unpublished project report.

The game is a simulation of the construction of a rock and clay-fill dam. Players, acting as project managers, had to select the equipment to use and the simulation would report on progress. There was uncertainty in the productivity of the equipment, its reliability, the amount of rainfall and its effect on the equipment.

In the late 1970s, Dr Mawdesley translated the game into Algol and produced a version which was stable enough to be used as part of a student exercise on planning, control and uncertainty. This was the first documented version of the game (Cullingford et al, 1979). Students worked in small groups (of two or three) to produce plans. They then submitted their ‘decisions’ on what equipment to use to the tutor or researcher who entered the data into the computer. The program ran overnight and the results were returned to the students the following day. The exercise lasted for most of the term with students monitoring and controlling their projects in parallel with lectures on related topics.

A typical decision sheet for the game is shown in Figure 5.1 and typical player’s outputs are shown in figures 5.2 and 5.3.

CONSTRUCTION MANAGEMENT GAME

DECISION SHEET

24

Group Number .... Decision Period Number ..1........

The Present State of Affairs:

Date now ...1 / 8 /1981

Height of Rockfill in dam ....0.00.... metres

Height of Clayfill in dam ....0.00.... metres

Total volume of rock now excavated ....0.... cu. met

(Codes 1 and 2 are on your last printout. If first decision period put zeros.)

Balance £ ..40000.....

Code 1 = ...0....

Code 2 = ...0....

New Input Decisions

Desired length of next decision period ......4.......... weeks

Species	This Decision Period			Hired		Fired	
	No.	Type	O/T	No.	Type	No.	Type
Scrapers	2	4	0	0	4	0	4
Lorries	15	6	0	0	6	0	6
Excavators	5	12	0	0	12	0	12
Rock Compactors	2	13	0	0	13	0	13
Clay Compactors	2	16	0	0	16	0	16
Lorry Haul Road Graders	2	18	0	0	18	0	18
Scraper Haul Road Graders	2	20	0	0	20	0	20

N.B. If none of one species has been hired or fired, fill in 0, 1. For overtime to be worked put 1. Otherwise put 0.

Level of rainfall at which you want the job blown up ..6.. ins/month

No. of wet-weather graders required, on call .....4...../inch/month

Gradient of lorry haul road ....0.1..........

Gradient of scraper haul road ....0.1..........

Change ....0.........

Figure 5.1 A typical decision sheet from an early version of the muck game

PLAYER 24 DECISION PERIOD 1

Week number : 1 Date of start: 1/8/1981

THE SPECIFIED LIMIT HES BEEN EXCEEDED ON THE RATE OF
CLAYFILL THEREFORE WORK STOPPED WHEN IT WAS REACHED

THE MAXIMUM RATE OF ROCKFILL WAS 68.42 PERCENT OF THE ALLOWED RATE

Week number : 2 Date of start: 8/8/1981

THE SPECIFIED LIMIT HES BEEN EXCEEDED ON THE RATE OF
CLAYFILL THEREFORE WORK STOPPED WHEN IT WAS REACHED

THE MAXIMUM RATE OF ROCKFILL WAS 65.85 PERCENT OF THE ALLOWED RATE

Week number : 3 Date of start: 15/8/1981

THE SPECIFIED LIMIT HES BEEN EXCEEDED ON THE RATE OF
CLAYFILL THEREFORE WORK STOPPED WHEN IT WAS REACHED

THE MAXIMUM RATE OF ROCKFILL WAS 68.28 PERCENT OF THE ALLOWED RATE

Week number : 4 Date of start: 22/8/1981

THE MAXIMUM RATE OF CLAYFILL WAS 0.00 PERCENT OF THE ALLOWED RATE

THE MAXIMUM RATE OF ROCKFILL WAS 0.00 PERCENT OF THE ALLOWED RATE

DECISION PERIOD NUMBERED IN WEEKS	1	2	3	4
SCRAPERS SELECTED	2	2	2	2
SCRAPERS OPERATIONAL	2	2	2	0
LORRIES SELECTED	15	15	15	15
LORRIES OPERATIONAL	14	14	15	9
EXCAVATORS SELECTED	5	5	5	5
EXCAVATORS OPERATIONAL	5	5	5	2
ROCK COMPACTORS SELECTED	2	2	2	2
ROCK COMPACTORS OPERATIONAL	2	2	2	0
CLAY COMPACTORS SELECTED	2	2	2	2
CLAY COMPACTORS OPERATIONAL	2	2	2	0
LORRY HAUL GRADERS SELECTED	2	2	2	2
LORRY HAUL GRADERS OPERATIONAL	2	2	2	0
SCRAPER GRADERS SELECTED	2	2	2	2
SCRAPER GRADERS OPERATIONAL	2	2	2	0
WET WEATHER GRADERS	4	4	4	4
RAINFALL IN INCHES	1.08	0.93	1.24	0.89
BLOW UP RAINFALL	1.50	1.50	1.50	1.50
CALCULATED ON THE BASIS OF PLANT POWER......				
POTENTIAL ROCK OUTPUT	15840.	15785.	16853.	5056.
POTENTIAL CLAY OUTPUT	9350.	8195.	7283.	.
POTENTIAL ROCK INTAKE	15840.	15785.	16853.	.
POTENTIAL CLAY INTAKE	9350.	8195.	7283.	.
ACTUAL MATERIAL PRODUCTION VOLUMES				
ROCK PRODUCTION	15840.	15785.	16853.	.
CLAY PRODUCTION	5394.	5649.	4055.	.
ROCK HEIGHT AT START	0.00	1.03	2.01	3.04
ROCK HEIGHT AT END	1.03	2.01	3.04	3.04
CLAY HEIGHT AT START	0.00	1.50	3.00	4.04
CLAY HEIGHT AT END	1.50	3.00	4.04	4.04
LORRY HAUL DISTANCE NOW (KM)	0.80	0.80	0.80	0.80
SCRAPER HAUL DISTANCE NOW (KM)	0.00	0.15	0.30	0.41

Figure 5.2 A typical output from an early version of the Muck Game

DECISION PERIOD NUMBERED IN WEEKS	1	2	3	4
SCRAPERS SELECTED	2	2	2	2
SCRAPERS OPERATIONAL	2	2	1	2
LORRIES SELECTED	15	15	15	15
LORRIES OPERATIONAL	15	14	12	15
EXCAVATORS SELECTED	5	5	5	5
EXCAVATORS OPERATIONAL	5	5	4	5
ROCK COMPACTORS SELECTED	2	2	2	2
ROCK COMPACTORS OPERATIONAL	2	2	1	2
CLAY COMPACTORS SELECTED	2	2	2	2
CLAY COMPACTORS OPERATIONAL	2	2	1	2
LORRY HAUL GRADERS SELECTED	2	2	2	2
LORRY HAUL GRADERS OPERATIONAL	2	2	1	2
SCRAPER GRADERS SELECTED	2	2	2	2
SCRAPER GRADERS OPERATIONAL	2	2	1	2
WET WEATHER GRADERS	8	4	4	4
RAINFALL IN INCHES	1.27	1.12	1.01	0.98
BLOW UP RAINFALL	1.50	1.50	1.50	1.50
CALCULATED ON THE BASIS OF PLANT POWER......				
POTENTIAL ROCK OUTPUT	16971.	15785.	12870.	16735.
POTENTIAL CLAY OUTPUT	6859.	6403.	2848.	5782.
POTENTIAL ROCK INTAKE	16971.	15785.	12870.	16735.
POTENTIAL CLAY INTAKE	6859.	6403.	2848.	5782.
ACTUAL MATERIAL PRODUCTION VOLUMES				
ROCK PRODUCTION	16971.	15785.	12870.	16735.
CLAY PRODUCTION	4004.	3701.	2848.	4038.
ROCK HEIGHT AT START	3.04	4.04	4.96	5.69
ROCK HEIGHT AT END	4.04	4.96	5.69	6.63
CLAY HEIGHT AT START	4.04	5.04	5.96	6.65
CLAY HEIGHT AT END	5.04	5.96	6.65	7.63
LORRY HAUL DISTANCE NOW (KM)	0.80	0.80	0.80	0.80
SCRAPER HAUL DISTANCE NOW (KM)	0.41	0.51	0.60	0.67

FINAL SUMMARY

THE ROCK HEIGHT IS 6.63 METRES
THE CLAY CORE HEIGHT IS 7.63 METRES

NEXT DECISION STARTS ON 26/ 9/1981

THE TOTAL AMOUNT OF ROCK NOW EXCAVATED IS 174496. CUBIC METRES

BALANCE AT START 580.00
MONEY SPENT 191220.
MONEY RECEIVED 121500.

BALANCE AT END -69140.0
LESS INTEREST 0.00

COST OF DECISION 1500.00

NET BALANCE AT
END OF DECISION -70640.0 POUNDS

CODE1=0 CODE2=0

WARNING: CONTRACT HAS ONLY 32 WEEKS TO RUN
OVER-RUN COST IS 2000. POUNDS PER WEEK

Figure 5.3 A typical summary output from an early version of the Muck Game

In the mid to late 1980s the program was translated into UCSD Pascal and the methods of operation changed. Instead of batch running the package overnight, student groups sat at the single desktop machine with the teaching assistant who input the students' decisions. The teaching assistant advised the students and helped explain where theory and application differed.

In the late 1990s collaboration between the Universities of Twente and Nottingham led to the game being translated into a MS Windows application under Borland's Delphi™ Programming language and environment. There was an initial attempt to make the interface such that the students could run it without the teaching assistant. Although previous versions had been used experimentally outside Nottingham, this version was the first to really be used in other institutions. Despite its design, it was largely used in the same way as the previous versions with a teacher or teaching assistant with the students.

This version of the game was used in The Netherlands and New Zealand to illustrate the planning and control cycle. The feedback was mixed being positive enough to maintain the courses but not sufficiently positive to extend them significantly. A journal paper describing this work was published (Al-Jibouri &

Mawdesley, 2001) and a brief synopsis of the case study in given in chapter 7 (section 7.1.1).

5.1.2 Description of the Muck Game

The game involves the student in a project to construct a 30m high dam of rock and clay based on an actual dam built in the UK in the late 1960s. The dam must be constructed within a specified time limit (typically 40 weeks) and project income is fixed and is awarded for each completed metre of rock and clay in the dam. The actual settings and project parameters can be customised to suit the audience. Examples of changes to project settings used to alter the teaching experience are given in chapter 8.

Figure 5.4: Screenshot showing form for selection of plant equipment

The student initially inputs a plan for the project. Once a plan has been created the student then selects appropriate resources to perform the work to this plan. The simulation can then be advanced by the student. The student can choose the rate of simulation (daily, weekly, fortnightly or four-weekly), or this can be set by the game umpire. Feedback on simulated progress is given and the student can choose to continue the simulation or take management action.

A number of simulated events such as resource availability, weather and accidents can influence project progress and students must be aware of these events and take appropriate control action to ensure progress follows the current project plan. In some instances this will involve re-planning the project due to a poor current plan or an inability to work to a plan due to events.

Recent use of the Muck game in very different roles at Nottingham University, UK and Curtin University of Technology, Perth, Australia are described in chapters 7 and 8 and are summarised in a recent paper by the author (Long et al, 2009).

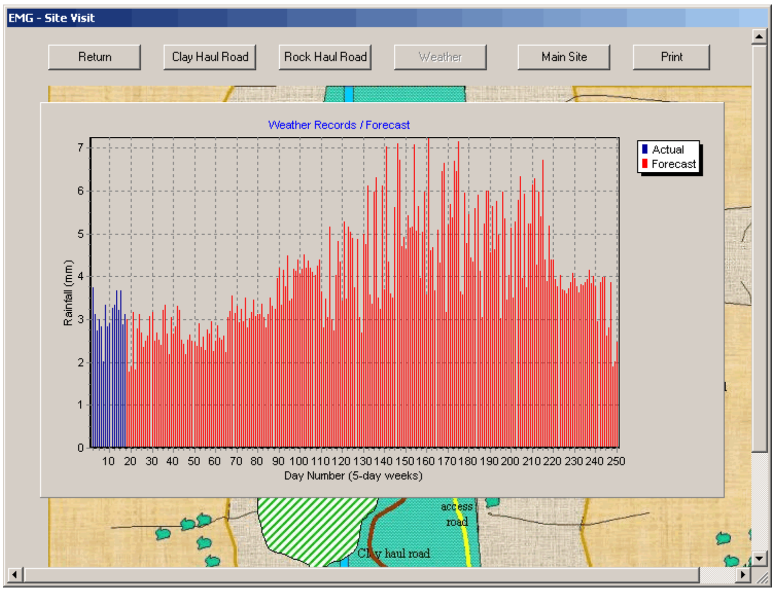


Figure 5.5: Muck game screenshot showing rainfall and site data

The game can be played over a local network enabling the students to use the games without supervision at a time of their choosing if required. In some instances, such as the Curtin teaching module or in previous industrial training, use of the games is supervised and kept within a fixed timeframe.

5.1.3 Shortcomings of the Muck Game

For the purposes of this research, there were various shortcomings of the game. In particular, the following issues were identified as possibly indicating that the game could not be used:

- The limited sources of uncertainty - As stated in section 5.1, there was uncertainty with rainfall and its effects on the productivities of the various pieces of plant and their reliability (this would manifest itself in terms of their availability). There was no way that the student could know this uncertainty before the game ran but it was possible to remove, almost all of, with some thought. This meant that the project was not very realistic.
- Shortage of management actions possible -The only management actions possible were to change the number and type of equipment working on the project or to change the maximum gradient of the haul roads. This is very limited and is not realistic.

- Lack of complexity - The project as modelled had six main activities excavation, transport and placement of rock and clay. Payers had to select the number of pieces of plant and the type of plant to carry out each of these six activities. Complexity came from the different volumes of material required at different heights, the varying haul distance and the interactions of the plant on each activity. Whilst realistic for simple project, this was not considered sufficiently complex to enable engineers to learn the management skills under consideration.
- No records were kept of student actions (except by students and in reports) - Whilst developing good practice for students, this had the drawback of not providing a basis for analysis for this research.
- Limited possibility of knowledge transfer between projects since only one project was defined. In fact, since the project definition contained some random variables (e.g. rainfall), it was possible to practice knowledge transfer but the level of realism was very low.
- Limited ability to prove that players understood how to transfer knowledge between projects and, indeed, what knowledge could be transferred.
- Lack of flexibility in many aspects of the game playing and the project.
- In all the versions described in section 5.1, the data for the project was 'hard coded' within the program and the sequence of play was defined by the program. This was, perhaps, the major restriction on the game being able to be used for this research.
- Calculation errors in code - In investigating the details of the game for this research it became apparent that there were several 'inconsistencies' in the calculations. None of these made the game unusable but they did add to the uncertainty in an unintentional manner and could cause players to lose confidence and hence interest. These inconsistencies would be more evident on repeated play of the game as planned for this research.
- Poor user interface. - The game was developed in the era of main frame computer and before the existence of personal computers with GUIs. Even when small computers became available, the game was not developed to improve the user interface. This meant, for example, that there was no graphical output available, no assistance for players and no simple input. All this detracted from the game being suitable for some of the aims of this research.
- The game only ran on stand-alone computers and therefore had no networking capability and only rudimentary security - This situation was not satisfactory as, if the aims of this project were to be achieved, it was necessary to enable players to access the game at times convenient for them

and in a manner which suited their work patterns. To do this with many players, both networking and security were required.

- Lack of standard control outputs as might be used on a project (and inability to generate these because of lack of data held and produced by the game)

5.1.4 Extensions and improvements to the Muck Game

Detailed analysis of the version of the game that existed in the early 2000s indicated that, if it were to be used to help achieve the objectives of this project, many of the shortcomings of the game described in section 5.1.3 had to be overcome. Given the existence of the game and the experience of running it in various forms, it was decided to make these alterations in parallel with developing other games.

The alterations made can be loosely divided into 4 categories:

- Creation of umpire and record keeping
- Improvement and extension of underlying model
- Improvement and extension of user interface
- Correction of mistakes

For the purposes of the research, it is the creation of the umpire and the keeping of records which was the most significant of these four. It is therefore described in greater detail in section 5.3.

Many of the modifications and extensions were carried out in parallel and over time but, for convenience, are described here individually. Except for where specifically noted otherwise all the modifications were made jointly by the Author and Dr Mawdesley as a contribution to this PhD research project.

5.1.4.1 Improvement and extension of underlying model

As noted in section 5.1.3, there was a perceived lack of complexity in the underlying model. This led to there being a limited range of management actions possible. It also meant that the analysis and reporting features were not as rich as those that would be encountered on even the simplest real projects.

In order to overcome this it was decided to extend the model to incorporate aspects other than the financial and physical ones on which the game had originally been based. Specifically supervision, safety, quality and environmental effects were incorporated.

Supervision was included in recognition that the game would be played at ‘project manager’ level. The project manager would employ people to oversee the day to day and hour to hour operation of the works. The cost of employing these staff would not be inconsiderable and the effect they could have on the site should also not be.

The supervision features were incorporated in a similar manner to the plant and equipment. The players were asked to choose a number of clay engineers, rock engineers, clay foremen, rock foremen, planners and secretaries (to represent the administrative staff).

The safety, quality and environment features were implemented by asking the player to decide how much to spend on training the staff on safety, quality and the environment and how much to spend on supervising those issues.

Within the project model, the number of different staff was used to alter the productivity of the equipment and change the likelihood of problems related to quality, safety and the environment. The problems, should they arise, give rise to extra expenditure and closure of the site. The cost and time are dependent on the severity of the problem which is also affected by the amount of spending on the various factors.

These effects are also related to the amount of equipment on the site, the weather and the physical state of the site.

The models used to determine the exact effects can be varied because of the flexibility introduced into the model with the inclusion of the defaults file described in table 5.2.

The original game did not have any facility for including a plan in the data. This meant that the players had to compare with the plans manually. In the version produced in the early 2000s, and used in The Netherlands and New Zealand, players were asked to put in a plan and were measured (in a rudimentary manner) against it. This version was created solely by Dr Mawdesley prior to the commencement of the research work described in this thesis.

In a real project, the plan might change several times during construction. To model this, the game was extended to enable a player to change their plan whilst still remembering the original plan which was agreed by the company. This provided a facility for including earned value analysis as part of the control mechanism.

One final improvement was made to the underlying model and this was the introduction of the possibility of defining the weather (rainfall) depending on the region of the world in which the project was being undertaken. Early versions of the game had all the rainfall figures hard-coded into the software. The game was changed to include the rainfall figures in the defaults file as described in table 5.2.

These changes, as well as improving the underlying model mean that the game can 'model' many similar but different scenarios (e.g. a dam set in the UK or a dam set in Western Australia). This means that the game can be used to determine if students are able to transfer information from one project to another.

5.1.4.2 Improvement and extension of user interface

Prior to the start of this project, some experience of running a Windows-based version of the muck game had been obtained through its use as part of a course in The Netherlands. Whilst feedback had been generally good, it was recognised that improvements to the user interface were necessary especially if, as intended in this research, the games were to run as a stand-alone exercise as a major part of a teaching module. The majority of these improvements (and extensions) were defined and implemented as part of this project prior to the main whole-module use of the game in 2006. The main alteration and extensions are shown in Table 5.1.

Improvement / Extension	Explanation
Assistance Files	In order to provide more information for students and in an attempt to ensure that students did not become 'stuck' in the game for lack of information, the 'Assistance files' were introduced. These are files which provide notes or PowerPoint presentations on specific aspects of the games or notes, PowerPoint presentations and web references to more general points which might help students.
Ticker Messages	Communication with the students either individually or in groups was seen as being an imperative. Ticker messages were introduced to provide this. Messages can be directed to all the players or to individual players. They are displayed when the player starts any run and re-displayed every time the game 'main screen' is displayed.
Facilitation of feedback from students on the games and their performance	In the same vein as the ticker messages, a feature to enable students to contact the 'head office' or the 'umpire' was added. These messages are called 'memos' and are plain text messages. The memos to head office are to enable the players to comment on their performance and that of the project. The memos to the umpire provide them with a facility to feedback comments to the academics on the games and their operation.
Improvements in planning interface	The interface of the Muck Game, despite having been improved considerably since the early versions was still rather difficult for students to manage. One specific area which required improvement was the input of project plans. This was initially improved in tabular / text format and eventually a graphical interface was developed.
Rainfall forecast	Some students had, in the early versions of the Muck Game, commented that they did not know what the rainfall would be and, since this could greatly affect the performance of the resources, a rainfall forecast feature was developed.
Increased flexibility in the Defaults file	The defaults file is the file that the umpire uses to control the parameters of the games. In very early versions of the games, all the parameters were 'hard coded' into the program. Later versions introduced the defaults file but with the changes envisaged as being necessary to the program for this research, it was decided to rewrite the defaults file to increase the flexibility and coverage of the file. Changes to the parameters are now much more convenient to make. Examples of the content of the defaults file are provided in the description of the Canal game (section 5.2)

Increase in complexity of decisions	The underlying model of the Muck Game relied on the player selecting the resources to move the rock and clay under a single uncertainty – the rainfall. This was sufficient for its original purpose but was not considered to offer sufficient challenge for the target students. Supervision and training were therefore included in the games. These require the players to select the amount of supervision (engineers and foremen) and the amount of training provided to staff. These have effects on the outcome of the project but less directly than the resources employed
Increase in measures of the project	Modern construction projects are not judges on financial aspects alone; safety, environmental impact and quality are also important. It was therefore decided to incorporate these aspects into the games. This was achieved through an extension of the underlying model of the operation of the project.
Increase in management actions required	The combined effect of the increase in complexity and the increase in measures was to increase the management actions required. This was judged to be necessary to test the hypotheses of this research as without such an increase it was likely that the students could very quickly (with few repetitions) learn how to play the game and not learn how to plan and control a project.
Increased verisimilitude In control	One aspect of the Muck Game that was important to the proposed research was its ability to model control information and actions that are used in reality. Many of the alterations described above are relevant to this. However, to improve this aspect even further, it was decided to include features to provide 'standard' features for earned value analysis and ratio control.

Table 5.1: Extensions and improvements to the Muck game

5.1.4.3 Correction of mistakes

Thorough testing of the game revealed several errors which, whilst not particularly serious could lead some players to distrust the package and consequently lose interest. The main errors identified were in the calculation of the finances and the haul distances.

The haul distances for both the rock and the clay are dependent on the gradients of the respective haul roads and are displayed on the progress screen. They were obviously wrong and, bore little relation to the distance required. They were, however, used by the players to calculate the number of the different types of plant to use. The errors had a consequential effect of making the outputs for the plant slightly in error. These were corrected and displayed to the players as the 'extra' distance caused by the gradient rather than the total distance.

The mistakes identified in the financial calculations were related to the initial payment made to the players and the retention held back by the client. The values of these were usually small (<£50000 in the £1.65m project) but could have disproportionate effects on the players. These were corrected.

5.2 Canal Game

The Canal game was developed to the 6th objective of the research (see section 1.2). The hypothesis was that the use of the Muck game was imparting some knowledge of construction management skills and methods to the students and not just teaching them to play the game. Knowledge learnt through the use of the Muck game should be transferable. The Canal game tests this by requiring the students to apply the skills learnt in the Muck game in a similar yet different simulated environment.

Screenshots from the Canal game are shown in figures 5.6 and 5.7. The user interface and general structure of the game is almost identical to the Muck game. In fact the Canal game could reasonably be described as a variant of the Muck game rather than a completely separate game. The key difference between the Canal and Muck games is in the nature of the construction projects they simulate.

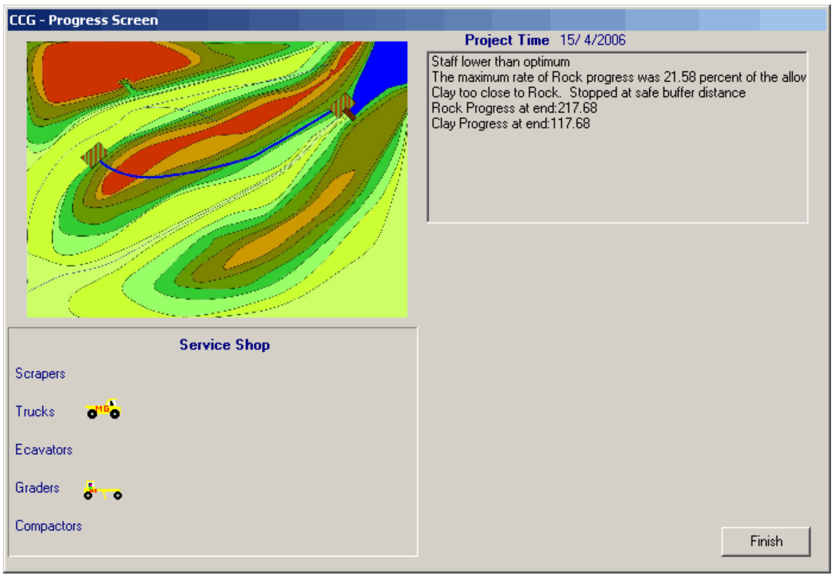


Figure 5.6: Canal game screenshot showing game progress

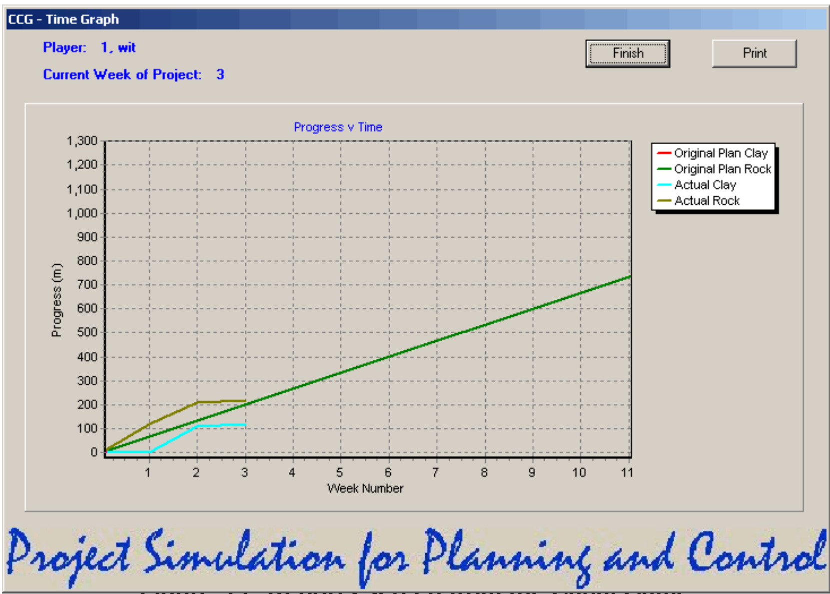
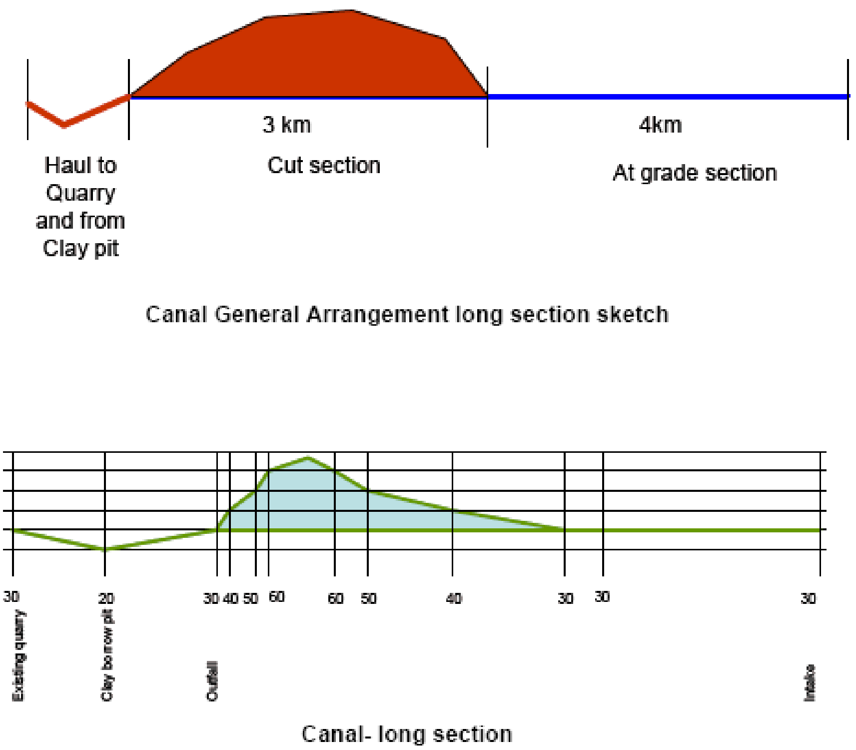


Figure 5.7: Reports screen from the Canal Game

The Canal game requires the player to excavate and line with clay 7km of canal within 150 weeks. It is a much larger scale project than that simulated in the Muck game. In addition the canal construction project requires the player to excavate through a hill for a significant portion of the 7km length. This gives the project a non-linear aspect requiring the player to adjust their resource levels and/or planning to reflect the vast differences in production levels required in different stages of the project. This non-linearity of the project can be seen in the cross-sectional profile for the project shown in figure 5.8.



Canal General Arrangement long section sketch

Canal- long section

Figure 5.8: Sketch and profiles for the Canal project scenario

The game is played in an identical manner to the Muck game with players creating a plan, assigning resources and advancing the simulation. However, the differences in the nature of the project lead to the game being played in a different way. The large amount of earth to be excavated early in the project combined with changed climate conditions forces the player to consider different types of plant equipment to utilise if they are to be successful in completing the project within budget.

The underlying simulation model of the Canal game was a redesign of the simulation in the Muck game. This redesign process enabled the production of a more complex and accurate simulation of the earth moving processes at the core of the simulation. Whether this difference in the verisimilitude of the two games would be evident to a player of the two games was not clear and would be investigated in the experimental work carried out using the games and described in chapters 8-10.

Item	Description
Version	The version number of the game. Used to check that the player is running the correct version
Security	Controls where the game uses the security files from the MCG Umpire (section 5.3.2)
Start	The start date of the simulation
File Locations	A number of settings to define where various elements of the game, e.g. data and media files, are located. Essential for running the game across a computer network
Feedback Options	Determines whether feedback is enabled and at what percentage progress points it is triggered at.
Initial Balance	Starting cash level for the player
Income	Defines the player's income for each completed 100m of rock and clay (Muck game=1m)
Warning Thresholds	A range of variables for determining the level at which warnings are triggered for a series of key values, e.g. summary measure or cash level.
Overheads	Fixed site overheads payable each day irrespective of resource levels.
Staff costs	The daily costs for the various types of supervising and administrative staff available
Fines & Events	These define the values of fine for transgressions for a number of potential problems. The probability of an event occurring that may lead to a fine is also defined here
Training modifiers	The effects of the various training budgets available on key variables such as quality of work and productivity can be effected by manipulation of the various settings in this category
Haul road settings	The initial conditions, effect of rainfall and impact of plant equipment on the haul roads can all be defined
Plant details	Properties of the various types of plan equipment used in the game can be defined here including names, reliability and productivity
Messages from HO	User definable message triggered by player performance are defined here along with the effects on gameplay, e.g. whether the player can continue the project or must review their decisions
Site Topography	Define the nature of the simulated scenario in terms of ground elevation and volumes of rock and clay production required at each point. Up to 20 points are definable.

Table 5.2 : Description of the contents of the 'defaults' (settings) file for the Canal game.

The Canal game was designed with greater flexibility in mind than the original version of the Muck game. The adaptations to the Muck game described in table 5.1 were included within the Canal game from its inception. These included many of the findings from the design and development of the BizSim and SubCon simulation games (chapter 4). An example of this would be that the features of the Canal scenario were embedded within the defaults file rather than hard-coded. The general arrangement of the project shown in figure 5.8 can be edited by the Umpire to alter the topography of the Canal route. A description of the main elements of the Defaults file for the Canal game is shown in table 5.2.

Note that the Muck game defaults file will contain the same meta-content as that shown in table 5.2 will some exceptions for the increased adaptability of the Canal Game. Items relevant only to the Canal game are shown in blue text.

5.3 Muck and Canal Game Umpire tool (MCG Umpire)

5.3.1 Creation of umpire and record keeping

These were the most important alterations to the game package from the perspective of this research since they enabled assessments of student performance and behaviour to be performed. They are described under four headings: Record keeping, Umpire, Player feedback and Security.

5.3.1.1 Record keeping

In order to provide data for analysis of player performance, it was necessary to collect as much as possible automatically every time the game was run. Two options were considered for this: the saving of the state of the game at each decision or the creation of a record file.

The state of the game was saved at each decision in order to enable players to stop playing and restart at convenient times. However, it was found that this provided insufficient information for the research. It was observed that players sometimes operated the game in a small number of decision periods – perhaps as few as five or ten for the whole forty-week project. This meant that the state would only be saved on a small number of days – perhaps as few as 10 out of the 200 days of operation. A considerable amount of data on progress, although not on players' decisions, was therefore lost. To store the state every day of operation, in the format used for running the game, would have been very wasteful of time and storage. It would also have been inconvenient for later processing.

For these reasons, it was decided to create a record file specifically for saving the state of the game. The record file is a flat text file. Each line contains parameters describing the state of the project. A new line is written every time there is significant change or action taken by the player. The actions which cause a line to be written to the record file are shown in Table 5.2. The code is used for analysis of the data allowing graphs to be produced showing states and player actions.

The information written in each record file entry is shown in appendix E but is not included here due to its size. The accuracy of the real numbers was selected as being realistic rather than a restriction of the internal storage. The game was altered to record this data whenever it was run irrespective of what actions the player took.

Code	State / Player action	Code	State / Player action
0	Run finished	222	Income – time
0	Run started	223	Expenditure – time
01	Main screen	224	Balance – time
01	Plan left – no changes	225	Income – expenditure
01	Plan left changes	226	Planned – actual
01	Plant decisions ignored	227	Estimated costs – time
01	Plant decisions left	228	Budget chart
01	Returned from assistance	231	BVWD chart
01	Site visit left	232	Current budget variance
11	Input estimate entered	233	Performance variance
12	Input plan entered	234	Efficiency variance
13	Input decisions entered	235	Budget revision variance
13	Supervision decision ignore	241	Planned performance
13	Supervision decision left	242	Actual performance
20	Report entered	243	Efficiency
30	Operate entered	251	Complete text records
30	Progress screen left	252	Land owner text records
31	Next day calculation	253	Clay text records
32	Five day calculation	254	Rock text records
33	Ten day calculation	255	Environment text records
34	Twenty day calculation	256	Safety text records
35	Total calculation	257	Quality text records
36	Single day calculation end	258	Text record search
37	Five day calculation end	260	Project text dump
38	Ten day calculation end	302	Plant during calculation
39	Twenty day calculation end	303	No work – rain?
40	Instructions entered	311	Daily progress
50	Assistance entered	511	Planning assistance
60	Site visit entered	512	Plan policy assistance
61	Clay haul road	513	Control assistance
62	Rock haul road	514	Finance assistance
63	Weather forecast	515	Risk assistance
64	Visit site main site	516	Fleets assistance
65	Visit site print	517	Definitions assistance
75	HO instructions left	518	Management assistance
78	Memo sent to head office	518	Other assistance
79	Memo sent to umpire	519	Management references
121	Making new plan	521	Output of plant assistance
122	Inspecting original plan	522	Haul roads assistance
123	Inspecting next plan	523	Plant fleets assistance
124	Inspecting previous plan	529	Equipment behaviour references
125	Plan printed	531	Scrapers assistance
211	Height – time	532	Compactors assistance
212	Overall performance –time	533	Graders assistance
213	Coefficients of traction	534	Excavators assistance
214	Rolling resistances	535	Trucks assistance
215	Volume of rock – time	536	Dozers assistance
216	Volume of clay – time	537	Loaders assistance
217	Rainfall – time	539	Plant type references
221	All money – time		Increase in day number

Table 5.3: Actions causing records to be written

5.3.2 Security

At the end of the 1990s the game had been developed as a single-user game for installation on individual computers. This limited the use of the package for the research described here. At the start of this project, it was therefore decided to extend the package to run on a network. This would have the advantage of enabling the information produced by the package and described in section 5.3.1.1 to be collected centrally. It would also enable much greater control to be exercised by the supervisory staff. However, it also required much greater attention to be placed on security to ensure that players' data was not corrupted either intentionally or otherwise.

Whilst the changes to the package to improve security were necessary to allow many players to play the game and took considerable time, they do not add to the actual data available and so are not described here.

5.3.3 The Umpire package

Running the game for a large number of players created organisational problems. Two alterations were necessary to overcome these. Firstly, all the set-up data was included in a data file (the defaults file described in table 5.2). This facilitated the use of security for a large number of players. Secondly, a package, the Umpire, was developed to manage the process of set-up and alteration. This package was then extended to include editing of the project and the analysis and display options necessary for this research.

Figure 5.9 shows the main screen of the Umpire package. The aspects related to this project are the Check Users and Monitor Performance for both the Muck and the Canal Games

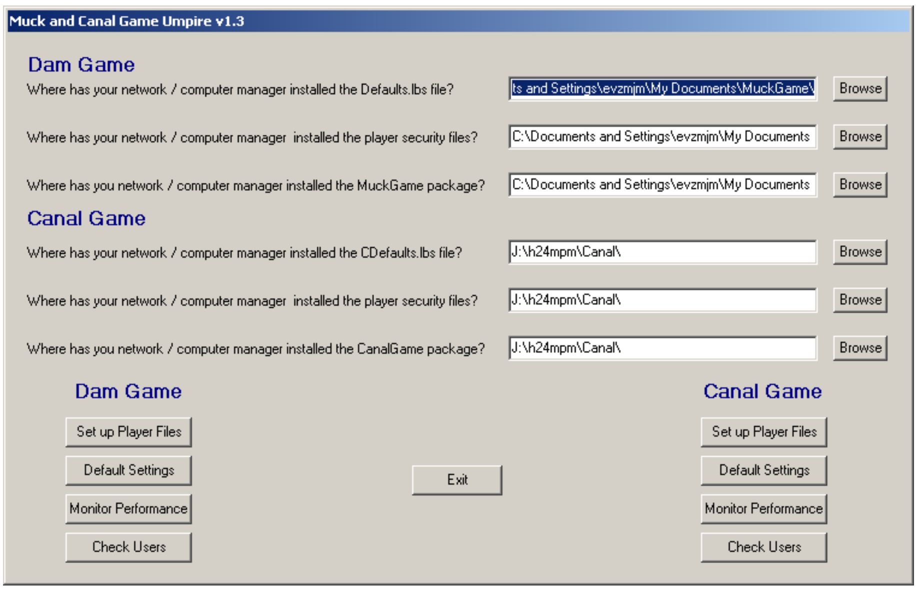


Figure 5.9: The Umpire main screen

5.3.3.1 Check Users

This option allows the user to check which players have been running the game and when. It displays the screen as shown in Figure 5.10.

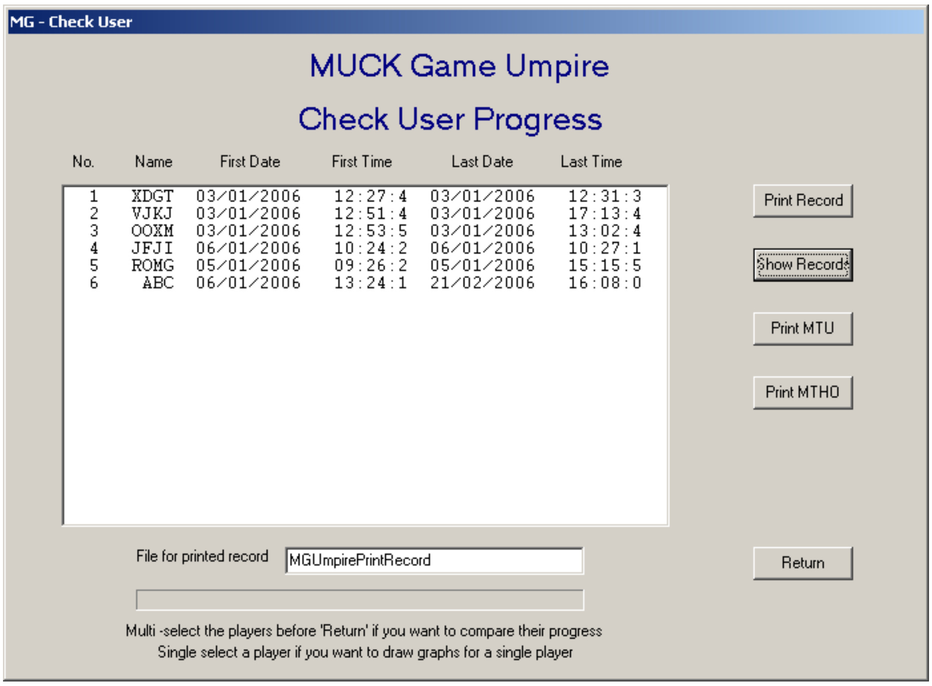


Figure 5.10: The Check User screen

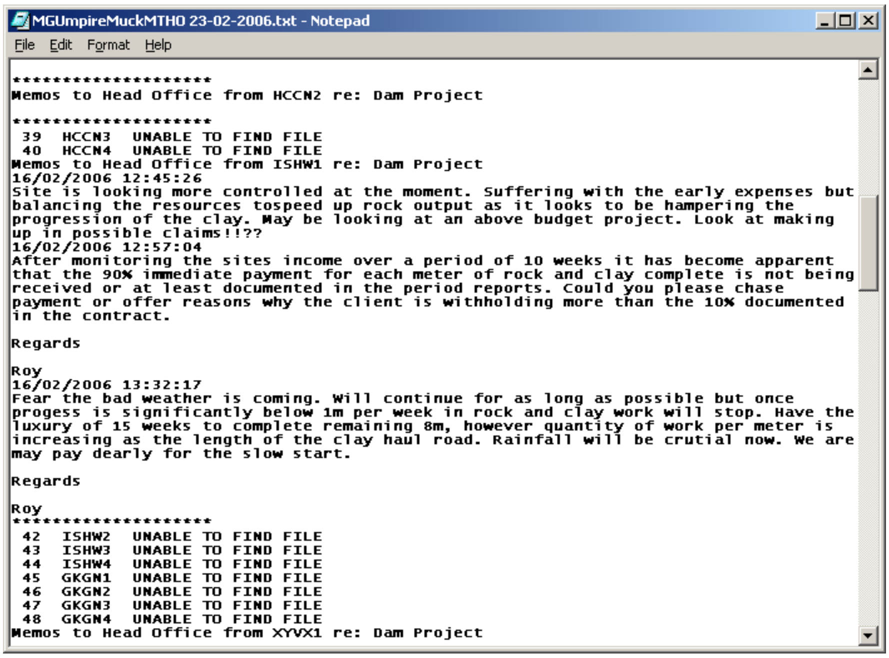


Figure 5.11: A typical set of memos

It also allows the supervisor to view and print all the memos written to both head office and the umpire (see Table 5.1 and section 5.3.3.3 for a description of these memos). These are displayed as shown in Figure 5.11.

5.3.3.2 Monitor Performance

This is the major addition to the umpire program produced for this research project. It provides a means of producing a wide variety of graphs for individual players and groups of players. The main screen for this section is as shown in Figure 5.12.

Initially it was intended to produce standard graphs showing performance in particular aspects of the game. However, during the initial testing of the facility, it was decided that a more flexible interface would greatly enhance its usefulness. This led to the development of the 'Custom Graph' feature illustrated in Figure 5.13. This was designed to allow the umpire / supervisor to plot graphs from any of the data stored in the record file.

The interface was designed to enable the production of a wide variety of graphs combining either several variables for one player or one variable for several players. It is also possible to plot several variables for several players but the resulting graphs are usually too complex to be of much benefit.

Figure 5.12: The initial Monitor Performance Screen

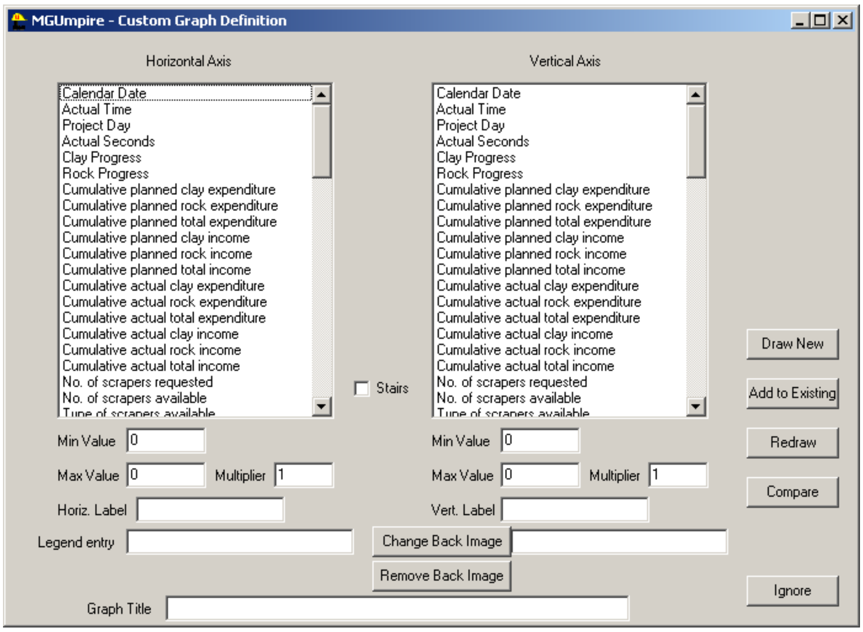


Figure 5.13: The Custom Graph Definition screen

Examples of the graphs can be seen in figures 5.14 and 5.15. Figure 5.14 shows a multi-line graph for a single player (the actual number of each type of plant working over the duration of the project) and figure 5.15 shows a comparison of the progress of several players (the clay progress in this instance).

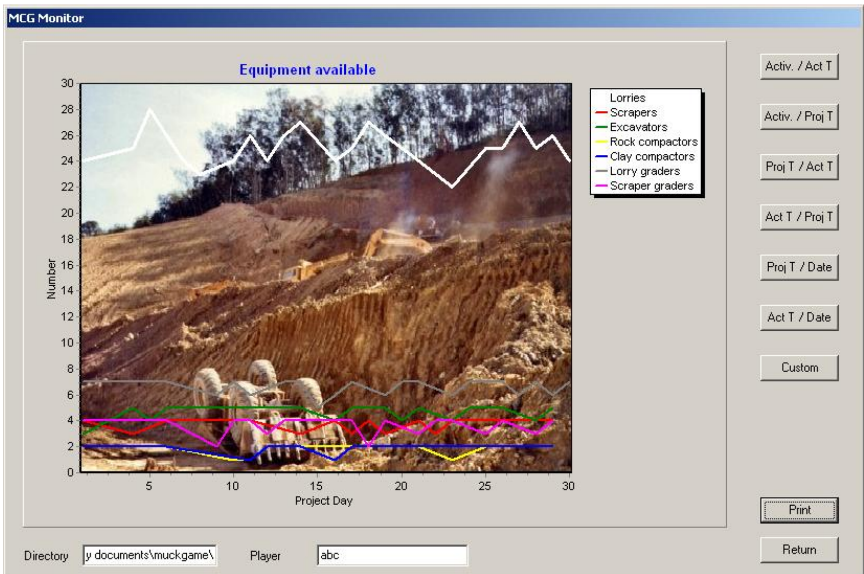


Figure 5.14: Typical multi-line single-player graph

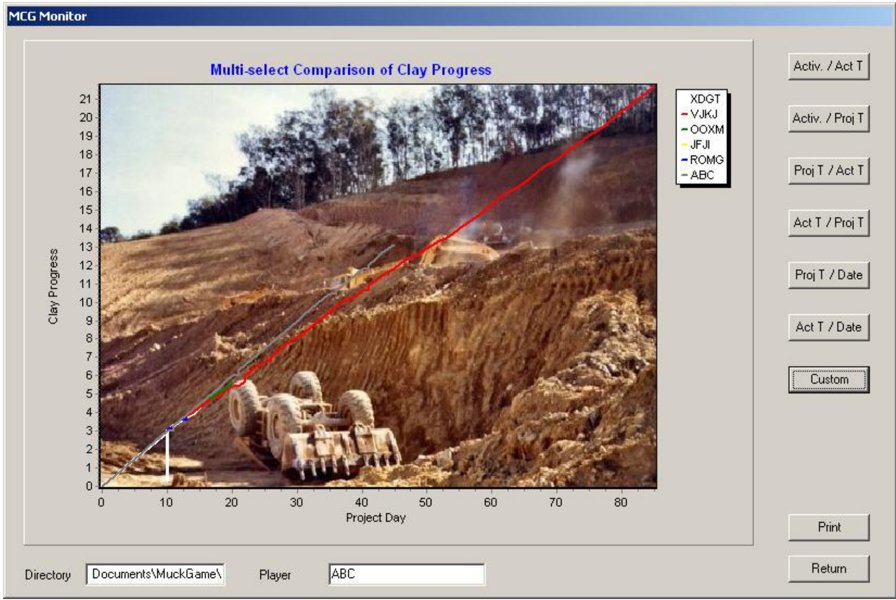


Figure 5.15: Typical multi-player comparison graph

5.3.3.3 Player feedback

The record file described in appendix E enabled a great deal of detailed information to be collected about the state of the project and the decisions made. However, nothing was put into the file to record the thinking and attitude of the players and how and why they are making decisions. This was because such information could not be collected automatically.

Two features were therefore introduced to collect non-numeric player-based information:

- Memo to Umpire and Memo to Head Office - These features were designed to capture information from the player during operation of the game. In particular, if players have a problem with the operation of the game they can write a memo to the Umpire (supervisor). If they have a problem with any aspect of the project they can send a memo to the Head Office (also the supervisor).
- In-line Questionnaire - This feature was designed to ensure that some feedback was obtained from every player of the games. When a project reached a predefined percentage of progress, a questionnaire as shown in Figure 5.16 was displayed.

Players had to fill in the form before the game would progress but they were able to simply leave the settings at the default values and press OK to proceed. The slider controls used to assign values in the feedback form have a value range of 0-10 and are set to the mid-point (5) by default. Obviously, there was no guarantee that the forms were completed meaningfully but students were asked to complete the forms as best they could. Results from this exercise are provided in chapter 9 (section 9.7).

It was debated as to whether to force the students to make changes to the forms before continuing but decided to leave the decision to the students to reduce student frustration and to avoid the input of false answers simply to enable the student to progress, An alternative proposed was to require the form to be completed but only once on completion of the project. However, it was felt that there was more benefit to be gained from assessing changes to student response during gameplay. This would provide a larger dataset and show changes in student opinions against performance. Results from the feedback form are appended to the user's *memo to umpire* file (<username>MTU.txt).

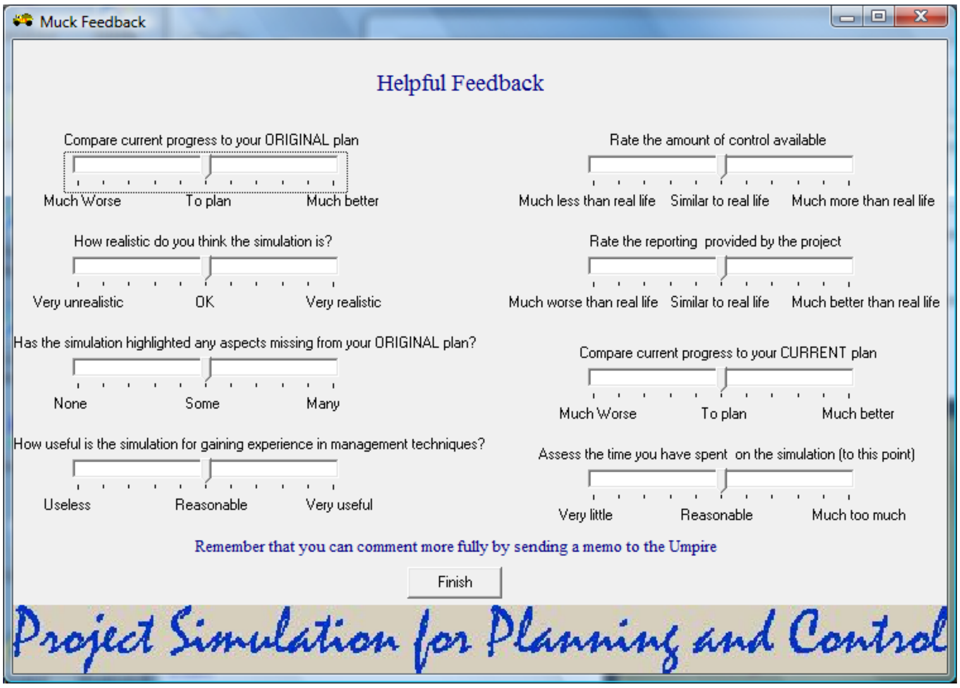


Figure 5.16: Player feedback form

5.4 Summary and key findings

The Muck game, a complex simulation game for teaching key aspects of construction management methods has been described in some depth. The Muck game was deemed to be an ideal candidate for answering the principal research aim and many of the objectives of this study (section 1.2) as it had a proven track record in teaching engineering students (see chapter 7). The game's history and development prior to this research was described. Shortcomings and limitations of the Muck game for the purposes of this research were described.

Extensions and modifications carried out to the Muck game in order to facilitate its use in this research have been discussed. These included changes to the user interface, underlying simulation model and alterations to the games structure. Adaptability and flexibility were greatly increased and the game was made suitable for repeated play (previously students had only run the game once). This has all demonstrated how an existing simulation or game can be updated to aid its reuse and can be applied in a different educational context.

A new simulation game, the Canal game, was developed using the Muck game as a template. This game utilises a similar interface and simulates the same basic construction processes but introduces non-linearity in the simulated scenario and is of a very different magnitude in terms of duration and size. The Canal game is effectively a variant (or ‘mod' in gaming terms) of the Muck game designed to test the transferability of knowledge learnt playing this type of educational simulation game. The Canal game utilises a more complex and accurate simulation model and is more flexible than the Muck game.

In addition to the two games, a software tool was developed in order to manage, control and track student learning in the games. This tool, the MCG Umpire, performs a variety of tasks including the setup and operation of the games across a computer network, methods for communicating between students and teaching staff, tracking of student activity during the simulation and methods for analysing this data. It would have been very difficult, if not impossible, to run the simulation games in an unsupervised manner without the presence of the MCG Umpire.

6. Initial experiment in the use of simulations and games for management education

In this chapter, the initial trial using simulations and games for teaching is described. The teaching module in which the work was carried out is described, as are the motivations behind its design and operation. The main focus of the chapter is in the aspects of the teaching module related to the use of the *BizSim* management simulation game described in chapter 4 (see section 4.1) and the feedback and results from running the module over a four year period. The lessons learnt from this experience are detailed here and were used to further develop the research programme as described in later chapters.

The teaching module that included BizSim as a source of teaching was initially titled *Science, Technology and Business* (STaB) but later changed its title to *Management for Positioning Technologies* (MPT) due to a forced alteration to the teaching schedule and content. The exact nature of these changes is described as within section 6.2 but both terms will be used throughout this chapter to refer to the teaching module where each is most relevant.

6.1 Background, motivation and aims of the teaching module

The STaB teaching module was initially proposed and designed as an optional teaching module for MSc students undertaking Master's programmes available from the Institute of Engineering Surveying and Space Geodesy (IESSG) at Nottingham University. The module aims (as described in the original module description documentation) are quoted below. Details of the specific elements of the teaching module are given in the section 6.2.

> *"This module is unique in the learning experience of most students in Science and Engineering. The approach taken is experiential which, in the context of this module, is afforded in two ways.*
>
> - *First you will hear presentations on the business process, including some from practitioners who run or work in businesses and those who provide services which are crucial to the success of a business.*
> - *The second strand of learning is that which you achieve by own efforts, by researching for and analysing information and by the*

development of an idea for an imaginary business exploiting some aspect of science or technology"

There was always an intention to include a simulation or game based coursework exercise as a key part of the module but in the module's initial year of operation there was not enough time to fully develop a bespoke simulation game. It was instead decided to purchase a licence for a commercial business management game or simulation to be used for the initial batch of students. This was also seen as a useful exercise in terms of researching the functionality and requirements of the bespoke management simulation game to be developed as part of the teaching module and this PhD programme. The commercial game used in the initial year of teaching was SESAMEE (The small and medium enterprise simulation) developed and marketed by the Orange Group Ltd. It is outside the scope of this chapter to provide a full description of SESAMEE, though a brief review of results and feedback from its use are included in section 6.3. SESAMEE is described and example screenshots of the simulation are given in Appendix A.

6.2 Instructional design

The instructional design principles behind both STaB and replacement MPT modules were largely identical and based on the aims and objectives outlined previously, the learning outcomes derived from these and the constraints on the module due such as timetabling, student numbers and resources available. Learning outcomes for the MPT module are shown in table 6.1.

From the early stages of developing the teaching module, the potential for introducing simulation of business enterprises was identified as a method for achieving some of the outcomes shown in table 6.1. Simulation was always intended to form an element of the teaching module in conjunction with more traditional coursework elements. The module was always to be assessed through coursework rather than examination elements. Many of the learning outcomes are directly linked to the use of the BizSim simulation game especially in relation to the transferable skill set shown in table 6.1.

The teaching module was designed to include both part-time and full-time Masters Students and therefore was designed to be run as a week long intensive course to ensure that part-time students could attend. The module was to be assessed via a range of coursework exercises with no examination required due to its vocational and business based focus.

Classification	Learning Outcomes
Knowledge & Understanding	1. Techniques for the appraisal of projects 2. Project planning techniques and their application to satellite positioning technologies 3. Project control techniques 4. Project finance
Intellectual skills	1. Evaluate critically businesses and projects 2. Propose new hypotheses based on incomplete evidence 3. Evaluate the applicability of management techniques to positioning technologies
Professional practical skills	1. Deal with complex issues both systematically and creatively 2. Make sound judgments in the absence of complete data 3. Communicate conclusions
Transferable (key) skills	1. Independently tackling and solving problems 2. Act autonomously in planning and implementing tasks at professional or equivalent level 3. Develop skills such as report writing, presentation skills, data collection and analysis 4. Exercise initiative and personal responsibility 5. Make decisions in complex and unpredictable situations 6. Evaluate own work and that of others against a set of known criteria

Table 6.1: Learning outcomes for the MPT teaching module [taken from University of Nottingham Catalogue of Modules]

The short and intensive nature of the course meant that some course elements would have to be achieved by the students working at a distance. In particular, the element of simulation based learning that is of interest to this thesis was to be carried out by students working outside the formal week of classes. This had a number of implications in terms of designing and operating the simulation exercise that will be furthered referred to in section 6.3. In terms of instructional design issues, it was critical that any simulation produced would be easy to use with only a brief introductory session. Direct contact with students during the simulation phase of the module may not be possible and any difficulties encountered by students would need to be resolved remotely (e.g. via telephone or email).

6.2.1 Science, Technology and Business

The design of STaB was driven by the aims and learning outcomes initially proposed when developing the teaching module. There were a number of institutional and logistical constraints on the instructional design such as the assessment requirements for MSc modules at the University of Nottingham and the need to include part-time MSc students in the course which meant that the course duration was more limited than a traditional teaching module. Direct contact with the students was limited to a single week of intensive teaching.

Module outcomes require the students to gain a good understanding of the key issues which lead to the commercial development of scientific and technological ideas and include an understanding of:

- The importance of the protection of discoveries with commercial potential and the processes involved.
- Business strategies and models including licensing and collaborations.
- Financing issues during the initial and subsequent stages of a small firm's development.
- Identification and assessment of potential markets for products and the marketing process.

The majority of the module was delivered by the Nottingham University Business School's Institute for Enterprise and Innovation. Their role primarily involved teaching the students about practical aspects of business planning and running a scientific or technological enterprise. The primary element of assessed coursework focused on the development of business plans for small and medium start up business enterprises. The teaching consisted of a series of lectures and presentations on the subject from both teaching staff and industry. Students were then tasked with producing a report analysing a company (a small public, i.e. plc, technology or science business) as a coursework element.

This was followed by the formation of students into working groups to develop business plans for presentation to teaching staff at the end of the week long module. Within each group, individual students take on the specific roles such as finance director, technical director or managing director for the businesses being planned. Once each group's business plan has been presented and the documentation handed in they are assessed and each student's work is marked (marks are assigned separately to the group's business plans and the oral presentation by each student.

After completion and presentation of the business plan the students received a brief lecture on simulation in general and the simulation game they were to use for the final coursework element which is the primary interest in terms of this thesis. Details of the coursework requirements relating to the use of the simulation game were given and the students were either (a) provided with a CD copy of the SESAMEE game, the means to run it and the associated documentation, or (b) asked for their business plans and contact details in order for the BizSim simulation of their business plan to be sent to them via email or postal service once it has been modelled in BizSim.

STaB was assessed 100% via coursework which consists of three main elements:

1. Assessment of group business plans (35%) and individual oral presentations (15%)
2. Company appraisal report (25%)
3. Report on simulated management exercise (25%)

The focus on preparing and presenting business plans (50% of total mark) is justified since the module's primary aim was to prepare graduates with the skills to devise and create their own scientific or technological enterprises. Developing and delivering an idea into a coherent business plan and the successful presentation of this plan to potential investors is critical to the learning outcomes.

The majority of teaching time was spent supporting the groups of students in developing their business plans. Reading and understanding of other aspects of the teaching are expected to be mainly carried out in the student's own time outside of direct contact with the teaching staff,

The purpose of the company appraisal report was for students to demonstrate that they had learnt and understood the teaching materials provided and lectures given on company reports and business/financial analysis of companies. They were given access to online databases on UK plc companies through the university library network. From this they assessed the performance and strategy of a company of their individual choice. Strengths and weaknesses of the company were highlighted along with summary advice for potential investors. Students were required to obtain and include up to date financial information and company reports with their report. This aspect of the module is important for any budding entrepreneur as investors would expect a certain degree of business literacy. Also, the ability to understand and analyse company financial statements is an essential prerequisite in the development of an individual's own such financial plans. Demonstrating an ability to identify the strengths and weaknesses of a company from an investor's viewpoint provides an excellent counterpoint to developing a business plan for potential investors.

The final coursework element, a report on the simulated management exercise, is the aspect of the module most connected to this thesis. Students are required to play through the simulation game provided (either SESAMEE or BizSim) and then write a short report to their fictional investors describing the simulated operation of their company. They are told only that the report should be concise, relevant to the audience and contain all the necessary information the investors would expect. They are expected to be able to determine the detailed content and style for themselves as a part of the coursework exercise. This reinforces the teaching on company and financial reporting that formed the motivation for the company appraisal coursework.

Included in the report on the simulation were the decisions taken and the reasons for them, events that occurred and the management response, company sales, marketing and resources over the simulated period and differences between simulated results and initial plan with analysis of the reasons for any differences. For the purposes of the SESAMEE simulation, students had to submit a brief plan of their aims and objectives for the business prior to receiving the simulation. This was based on the detailed company information provided with the SESAMEE software and is required for the students to be able to assess their performance against an initial plan.

A module information document provided to students for the initial year of running the STaB module with the SESAMEE simulation software is provided in appendix B. This describes the aims and objectives of the module and the requirements of the students in this year.

6.2.2 Management for Positioning Technologies

Changes forced upon the teaching led to the development of the MPT module from the basic template used in STaB. It was no longer possible to provide the teaching on business planning through the University's Business School as changes to the schedule for their teaching meant that it will no longer possible for part-time MSc students to attend this aspect of the course. Its revised schedule also clashed with the scheduling requirements for other modules in the MSc programme.

In order to continue to run the teaching module it was necessary to redesign and rename the module (as the business school were still operating the core of the module albeit to a difference teaching schedule). There was deemed to be sufficient experience of management (focussed on project and construction management) within the school of civil engineering to deliver an altered teaching programme to the students whilst maintaining the core learning outcomes and objectives of the STaB module.

The revised teaching module was titled Management for Positioning Technologies and was delivered entirely by the School of Civil Engineering and the Institute of Engineering Surveying and Space Geodesy (IESSG). In essence, MPT is almost identical to STaB with some exceptions:

- More emphasis on general planning and control of businesses and projects rather than a narrow focus on developing business plans. This was due to the teaching expertise available and a desire to increase the employability of graduates in the wider business market.

- An additional coursework element was added to the module. This required the students to research business planning prior to the start of the formal teaching. Students are tasked to write a 2000 word report discussing the aims, objectives, content and style of a business plan. The coursework deadline was the start of the week long teaching period. The purpose of this was to ensure that the students have some background knowledge on business planning. The initial lecture period is then used to review the knowledge they have learnt and bring all students up to an acceptable level of understanding prior to the start of the group-based business planning exercise.
- Module assessment was changed to reflect its revised focus and to allow for the additional coursework element mentioned. The breakdown of marks by coursework elements is as follows:
    - Coursework 1 – Report on business planning (30%)
    - Coursework 2 – Group based business plan development project (30%)
    - Coursework 3i – Appraisal of two companies (20%)
    - Coursework 3ii – Report on simulation of business plans using BizSim software (20%)
- Guest lectures from local engineering and surveying SME's rather than the wider range of business involvement in STaB. This provided a view of business more applicable to the students.
- Higher staff/student ratio than STaB as students involved were only those registered on the MPT module. This led to a more open and informal teaching environment where student involvement in the learning process was increased.
- An increase in lectures and direct teaching time during the week long module. Under MPT each morning is taken up with lecture and tutorial based teaching of business management, planning and analysis concepts.
- Afternoon sessions consist of group based working by the students on the development of their business plans.

The timetable for the module is given in appendix K.

6.3 Module operation and results

STaB was taught to students in the academic years 2002/2003 to 2003/2004. The revised MPT module ran from academic years 2004/2005 to 2005/2006. The module did not continue after this due to a redesign of the Masters programmes within the IESSG.

The number of students taking the module ranged from 7 (02/03) to 24 (03/04). The high number of students in academic year 03/04 was unusual and meant that there had to be five groups of students each with 4-5 members. All the other years of operating the module were with around 3-4 groups of students (each with 3-4 members).

As previously described there were some significant differences in the operation of the STaB and MPT modules. As the MPT module was run entirely within the School of Civil Engineering, greater control over the teaching content and greater contact time with the students were possible. This allowed the teaching staff to observe the development of the group's business plans from the initial formation of the groups. This eased the process of creating the bespoke simulations for each group as it led to greater overall development time and teaching staff were able to clarify details of the business plans with the groups of students during development.

In some instances this led to changes to the *BizSim* data model to incorporate features of a group's plan. In other cases, queries from teaching staff on the developing business plan led to a change in a group's plan. It must be noted however, that teaching staff did not attempt to steer a group's business plans into a format more suitable for the purpose of simulation. Staff involvement was purely to clarify a group's intention with regard to their business plan which often highlighted issues that the group had not addressed.

The stochastic nature of BizSim meant that some students had a much easier experience in running their simulated company's than others. The prevalence of positive or negative events is not directly related to student actions in all instances and 'bad luck' could mean a student encountering numerous negative events (e.g. poor product reviews, increased competition or increases in supplier's pricing structures) through no fault of their own management methods. This did not adversely affect the students as they were not being assessed on their performance at the simulation directly but in their ability to analyse their performance and make reasonable management decisions in light of feedback from the simulation.

6.3.1 STaB Year 1 – Academic year (2002/2003)

As stated in section 6.1, the initial year of operation did not utilise BizSim but instead employed the commercial SESAMEE simulation (Appendix B for further details). There were only 7 students taking the module in this year. Students all worked individually with the SESAMEE simulation. After a brief session introducing the workings of the simulation and business scenario it simulates, students were provided with copies of the simulation and the code required for them to access the simulation.

On completion of the simulation students wrote a brief report on the experience which was returned along with the data file created on completion of the simulation. Data collected was not analysed except to confirm that the students had run the simulation as required and to examine their performance in broad terms. All students completed the exercise to varying degrees of success and produced reports to the required level of competence and completeness.

Feedback from the students on the module was generally positive overall with a few points raised in relation to the style of teaching provided by the business school which the students were unfamiliar with. In relation to the use of the simulation, students' views were that they enjoyed this type of exercise but thought that they did not receive enough information and support to run the simulation initially. A few students highlighted the issue that the simulated business environment in the SESAMEE game did not bear much relationship to the business environment at which the STaB module was focused (surveying, navigation and positioning technology and methods). This feedback was expected and was remedied by the introduction of the BizSim software in subsequent years.

The use of the SESAMEE software was a useful exercise in identifying many of the logistical, technical and educational implications of using simulation games in this way. Despite extensive testing, a couple of students had technical problems running the software. One of these was easily resolved by email but the other required the student to be sent a new version of the software and to install the software on a different machine. This finding was important as it showed that even with a commercial piece of software that had been fully tested and used by a variety of users, technical issues can still occur. It also highlighted the difficulties in correcting technical issues in a distance learning exercise as were anticipated in the initial instructional design for the module (and referred to in section 6.2).

6.3.2 STaB Year 2 – Academic year 2003/2004

There were 24 students who took the module in this year (although one student did not attend the week long course due to a family bereavement) and this was the first year that BizSim was used as part of the module. Student groups were formed during the business planning exercise at carried out at the business school. Five groups of between 4-5 members were created.

The large increase in class size (this was the largest class size in the four years of running the STaB/MPT modules) combined with the introduction of BizSim greatly increased the difficulty in running the simulation element of the module but led to a number of important findings in terms of teaching through the use of simulation games.

The constraints of the STaB module (section 6.2.1), meant that students developed their business plans independently of the teaching staff within the school of civil engineering. Each student group was tasked with presenting the business plans developed during the element of the module operated by the business school and were assessed on the presentation of their plans. This occurred on the final day of the week long course along with a brief presentation of BizSim using a sample simulated company developed.

Business plans and associated documentation were collected from each group and used to generate BizSim simulations. Each group's business along with a brief description is given in table 6.2. Some adaptation was required for all simulations to balance gameplay, simulation and learning aspects of the exercise.

However, the business plan of one group was deemed unsuitable for simulation. The business was based on a licensing agreement with Nokia for the sale of a product/application to be used with that company's products. The nature of the contractual agreement between the company and Nokia would have made any simulation exercise pointless since there were no significant risks attached to the business once it was accepted by Nokia. Without the agreement with Nokia, the business was not viable without extensive adaptation. It was therefore determined to inform the group members of this and provide them with a simulation based on a modified version of their business plan. This would provide them with a business they were still familiar with whilst providing them with a simulated experience of management that could not be performed with their own business model.

A graph showing the comparison between assessment marks for the simulation exercise and those for the whole teaching module is shown in Figure 6.1.

It can be seen from Figure 6.1 that there is generally a correlation between the simulation assessment marks and the overall assessment mark. There are however, some notable exceptions where performance at the simulation is poor in comparison to their overall assessment mark.

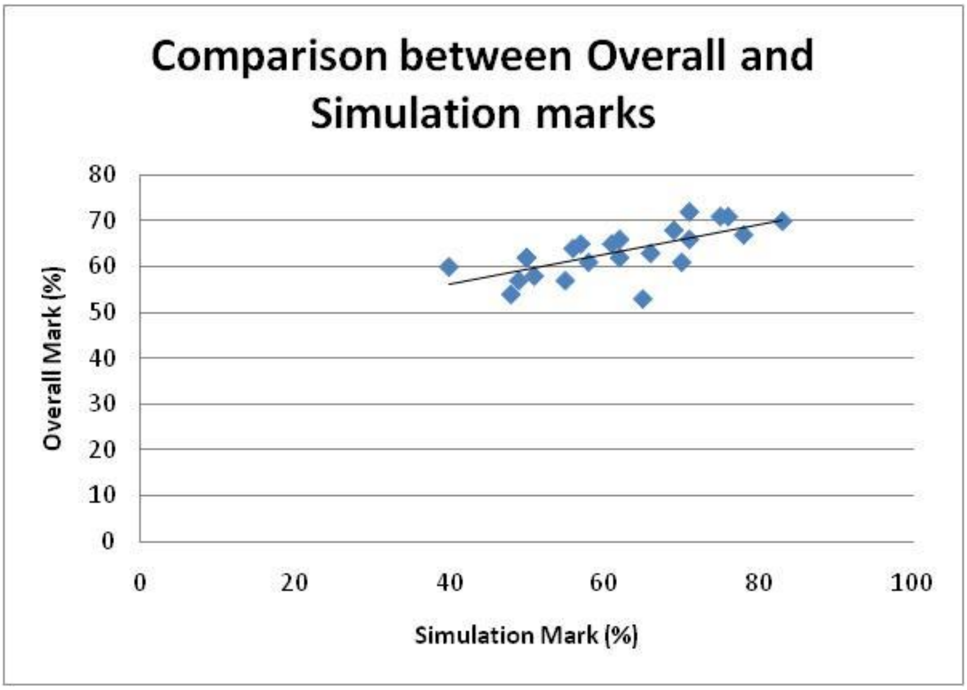


Figure 6.1: Comparison of assessment marks from simulation exercise and whole module

The limited time available for modelling student simulations from their business plans was a significant concern and constrained the modelling process. It was however, unavoidable due to the temporal constraints on the STaB module enforced by the Masters programme and other teaching modules within it. It is thought that had additional time being available for the modelling process then the business plan that had to be significantly adapted for simulation could have been modelled more closely to the students' original business plans.

All simulations were completed to varying degrees of success by the students. It was noted that there was a wide divergence in simulated performance even between some group members. This was partially due to the stochastic nature of BizSim and partly due to differences in management skills of the students.

It was noted that some students were inflexible in their approach and stuck to their business plans even when there was evidence that the plan was not working. Other students showed signs of micromanaging the simulation and moved rapidly away from their business plans adopting a very reactive style of management.

By the end of the simulation most students had learnt something about their business plans and the types of difficulty in managing a company as was recorded in their feedback and noted in their reports on the simulation through the coursework.

A number of important lessons were learnt in relation to this initial year's use of BizSim. The constraints of the limited time available for the modelling process were fully appreciated and lead to changes to the BizSim software model and creator tool for use in subsequent years.

6.3.3 MPT Year 1 – Academic year 2004/2005

This was the first year of running the revised MPT module. Eight students took the revised module (3 part time and 5 full time students) and were split into two groups (students were allowed to form their own groups) on the first day of teaching (see appendix K for the timetable for this year). A traditional lecture based teaching programme was carried out in the mornings of the week of teaching and the group based work developing business plans by the students was performed in the afternoon sessions.

The early involvement of the teaching staff with the students was very useful for the development of the simulations. The researcher had access to the student's business planning from their inception and was able to clarify the student's aims and objectives for their businesses. It was also possible to question the students on their business plans during their development which assisted the students from a learning perspective and also helped the development of the simulations. This much earlier contact with the students meant that the development of the simulations could commence earlier than in previous years, easing the difficulties of creating the simulations within the deadline and improving the content of the simulation.

As can be seen in table 6.2, student performance at the simulation varied quite dramatically with one member of each group performing excellently whilst other produced satisfactory results. This was not related to their performance at the simulated exercise but in terms of their ability to produce a useful, clear and coherent report on their simulation.

ID	Group	Simulation Coursework Mark (%)
1	GetUThere	90
2	GetUThere	50
3	GetUThere	60
4	SolarSolutions	85
5	SolarSolutions	65
6	SolarSolutions	60
7	SolarSolutions	60
8	GetUThere	50

Table 6.2: Student groups and assessment marks for simulation

6.3.4 MPT Year 2 – Academic year 2005/2006

Nine students took the module in its final year. These were split into three groups of three students as it was felt that a group of five would be too large. The revised module structure also made it easier to generate the simulations as described in the previous section (section 6.3.3) which meant that it would not be a problem to produce the three simulations within the temporal constraints of the module. Table 6.3 shows the students and their groups for this year.

ID	Group	ID	Group
1	ForwardMomentum	6	X-Trak
2	TerrainMaster	7	ForwardMomentum
3	TerrainMaster	8	ForwardMomentum
4	ForwardMomentum	9	TerrainMaster
5	X-Trak		

Table 6.3 : Students and their groups in academic year 2005/2006

In-game feedback forms identical to those used with the Muck game and described in chapter 5 were added to BizSim in this year to bring it into line with the plan for the ACPM module which commenced in this academic year. Data collected through the forms was collated and analysed. All questions are answered by positioning a slider control to the level of response appropriate. Responses are annotated with examples for the extreme and mid-point values and the range of values possible goes from 0 to 10 with all sliders positioned at the mid-point value (5) by default. The questions asked in the form are shown in table 6.4.

The response values for game type questions are of the form where low values equal a negative response and high values equal a positive response. For performance type questions, a mid–range value represents optimum response and high and low values represent opposing extremes of divergence from their business plans. Figure 6.2 shows the mean average values from all the completed questionnaires.

Of the eight questions, question seven receives the highest value response on average indicating that students are happy with using BizSim. This is a positive result and confirms the design decisions made it keeping the game and its interface as simple as possible to ensure that students did not encounter difficulties. This was essential since problems would be more difficult to resolve in a distance learning exercise as was noted during the initial two years of running the module.

ID	Question	Response			Question Type
		Value 0	Value 5	Value 10	
Q1	Compare current progress to your original business plan	Much Worse	To plan	Much better	Performance
Q2	Does the game provide a realistic simulation of your business?	Very unrealistic	OK	Very realistic	Game
Q3	Has the game highlighted any aspects missing from your plan?	None	Some	Many	Performance
Q4	Is the game a useful tool for assessing your business plan?	Useless	Reasonable	Very useful	Game
Q5	Rate the amount of control and interaction available	Much less than real life	Similar to real life	Much more than real life	Game
Q6	Rate the reporting and feedback available	Much less than real life	Similar to real life	Much more than real life	Game
Q7	Is the game user-friendly?	Not at all	Reasonably	Extremely	Game
Q8	Assess the game length (time you spent) to this point	Very little	Reasonable	Much too much	Performance

Table 6.4: Feedback questions used in the in-game feedback questionnaire.

Questions one and six were the only ones receiving a low response of any significance. The remaining questions all received mean response levels around the median value indicating neutrality or satisfactory performance.

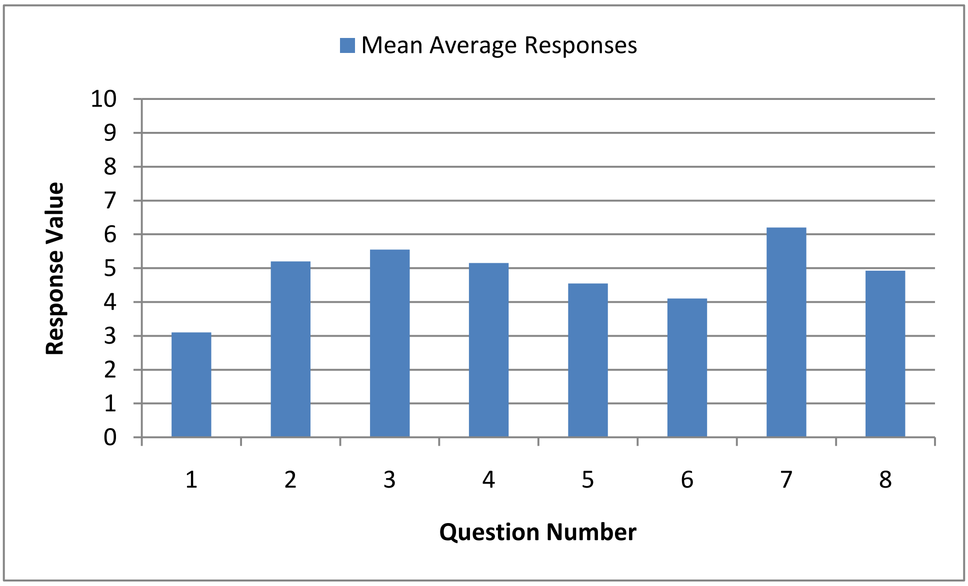


Figure 6.2: Mean responses for all in-game feedback

The low response for question one shows that the students found that the simulation diverged from their performance significantly in general. This seems to demonstrate that the experience has been effective as a teaching experience. It has caused the students to reflect on their business planning and has highlighted differences between their plans and potential events. This appreciation of the potential events that could occur and the limitations of business planning was one of the driving motivations behind the use of BizSim and it is therefore a positive result for the experiment.

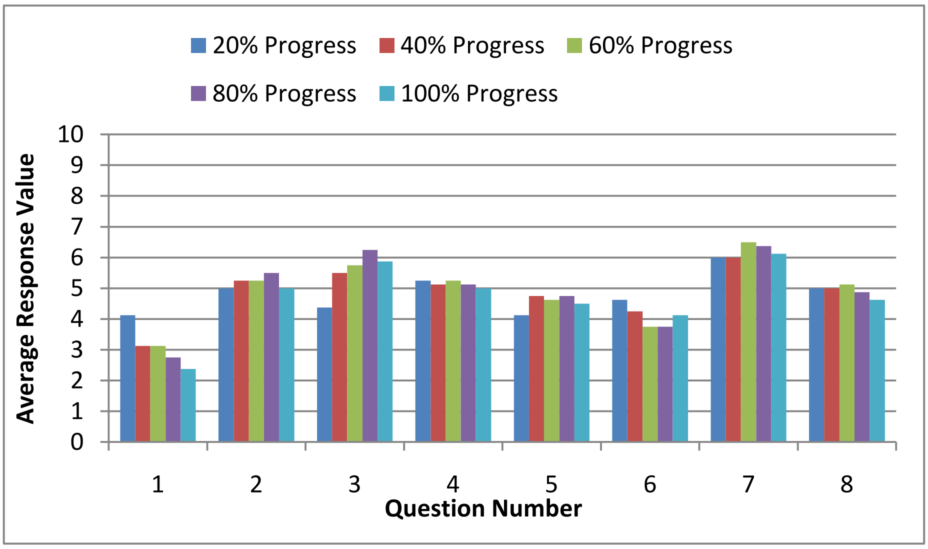


Figure 6.3: Average responses to in-game feedback classifed by progress

It can be seen from figure 6.3, that there is a definite decline in student's opinion of their performance to the original business plan as the simulation progresses (question 1). This corresponds with the increasing value of response for questions 3 showing that students identify elements missing from their business planning as the simulation progresses.

The most positive response relates to question 7 showing that the students feel that the game is easy to use. Other responses to game type questions (questions 2,5 and 6) show that students find the simulation an acceptable facsimile of their business plan and that they feel that they should have greater control over the simulation and that reporting and feedback mechanisms could be improved. Feedback specific to an individual player in respect of these issues is shown in section 6.4.2.

6.4 Analysis of student learning

It seems evident from student feedback to the use of BizSim in the STaB/MPT module that the type of learning experience delivered can be both effective and engaging. It extends the more traditional lecture based (tell-test) approach to teaching and learning in the rest of the module providing a method for examining the potential implementation of the student's business plans in a way not traditionally possible in the teaching of business planning and management. However, qualitative feedback from students is too subjective to confirm the utility of the approach and the number of students involved is not high enough to represent a statistically significant sample population.

This section concentrates on analysing the learning delivered through the use of BizSim within the STaB/MPT module only. In order to achieve this aim a variety of data sources were examined such as the coursework reports, simulation data files and overall student results from other elements of MPT.

Lessons learnt from analysing the data, both in terms of the development of simulation games and in their use in a teaching and learning context are given here. These formed a key role in the development of later work as part of the PhD research as described in chapters 8 to 10.

The nature of the teaching module made it impossible to assess the student's use of BizSim in the classroom as the coursework element it formed the basis of was performed outside the formal teaching schedule. As one of the coursework requirements the students were to submit a data file produced by BizSim along with their report on completing the simulation. This file is produced on completion of the simulation and contains data on the simulated companies, markets, events and student actions that occurred during the simulation.

The stochastic nature of the BizSim simulation game makes it difficult to directly compare performance by a group of students on the same simulation. Random events can have a significant effect on the ability of a player to complete the simulation with identical results even assuming they made identical management decisions. However, comparing those students running the simulation is useful to examine the differences in their management decisions, reactions to events and analysis of their performance.

6.4.1 Case Study 1 - Year 03/04 Student ID #3

This example is for a student exhibiting average performance both in terms of the simulation exercise and for the module overall. The student ran the I-Spy simulation and charts of their performance are shown in figures 6.4 and 6.5.

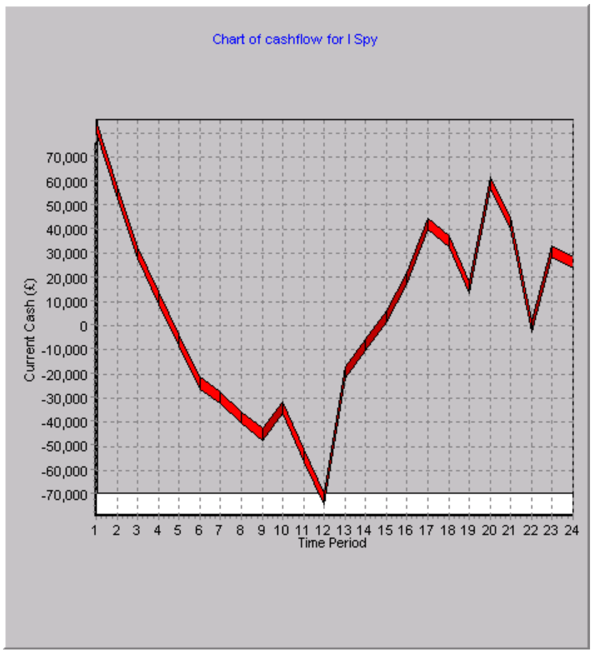


Figure 6.4: Chart of cashflow during simulation for year 2 student #3

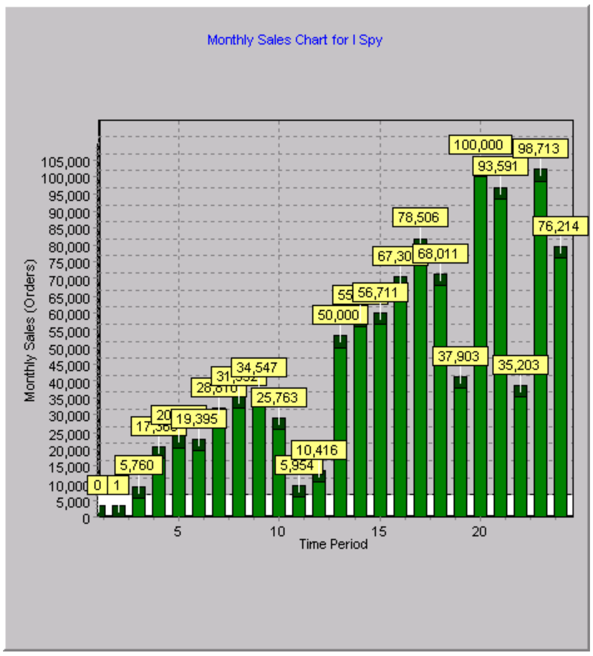


Figure 6.5: Monthly sales chart for year 2 student #3

Figure 6.4 shows the student's poor performance in the initial year of the simulation. By cross-referencing with figure 6.5 it can be seen that the poor profitability is due to a lack of sales in this initial year. Analysis of the data from the simulation and their report on their performance indicates that mistakes were made initially and there was then a period of experimentation and micro-managing which did not produce good results. The student then seems to realise that their monthly changes to their business are perhaps harmful and reflects on their performance and makes changes which lead to the improvements in sales and profitability in the second year of the simulation.

The student's conclusion and feedback on their experience is positive but shows that they were unable to fully manage and control the simulation:

> *What a "roller coaster ride". When you think you have "got it right" something new comes along and you need to tackle another aspect. Once I got going, I found it quite exciting and was eager to see what the next month's figures brought, but I now definitely know why I never started my own Survey Company.*

[Student #3 Conclusions of coursework report 2004]

6.4.2 Case Study #2 – Year 05/06 Students #1 and #8

This example looks at two students (ID 1 and ID 8) from academic year 2005/2006. Both students were in the group running the GetUThere simulation. Student #1 received 90% for the report on the simulation and student #8 received 50%. However, it can be seen from the charts of their individual performance that both completed the simulation profitably. Student #8 received a lower mark because their analysis of their performance was not as strong as student #1 and the report of their performance had significant omissions and weaknesses.

Figure 6.6 shows four performance charts for student #1 and figure 6.7 shows the same charts for student #8. In both instances a large dip in cashflow is shown in month 23. This is due to the payment of Corporation Tax in this month which was high in both instances due to the innate profitability of the GetUThere simulation.

As can be seen from figure 6.6 and 6.7, student #1's performance was significantly better than student #8. Overall the two years of the simulation student #8 only managed to achieve a 1-1.5% market share whilst student #1 achieved a market share in excess of 22%, though this then dropped back to 20% due to an event increasing competition in the market. Student #8 did not suffer this event since their market in general was less profitable due to their management decisions.

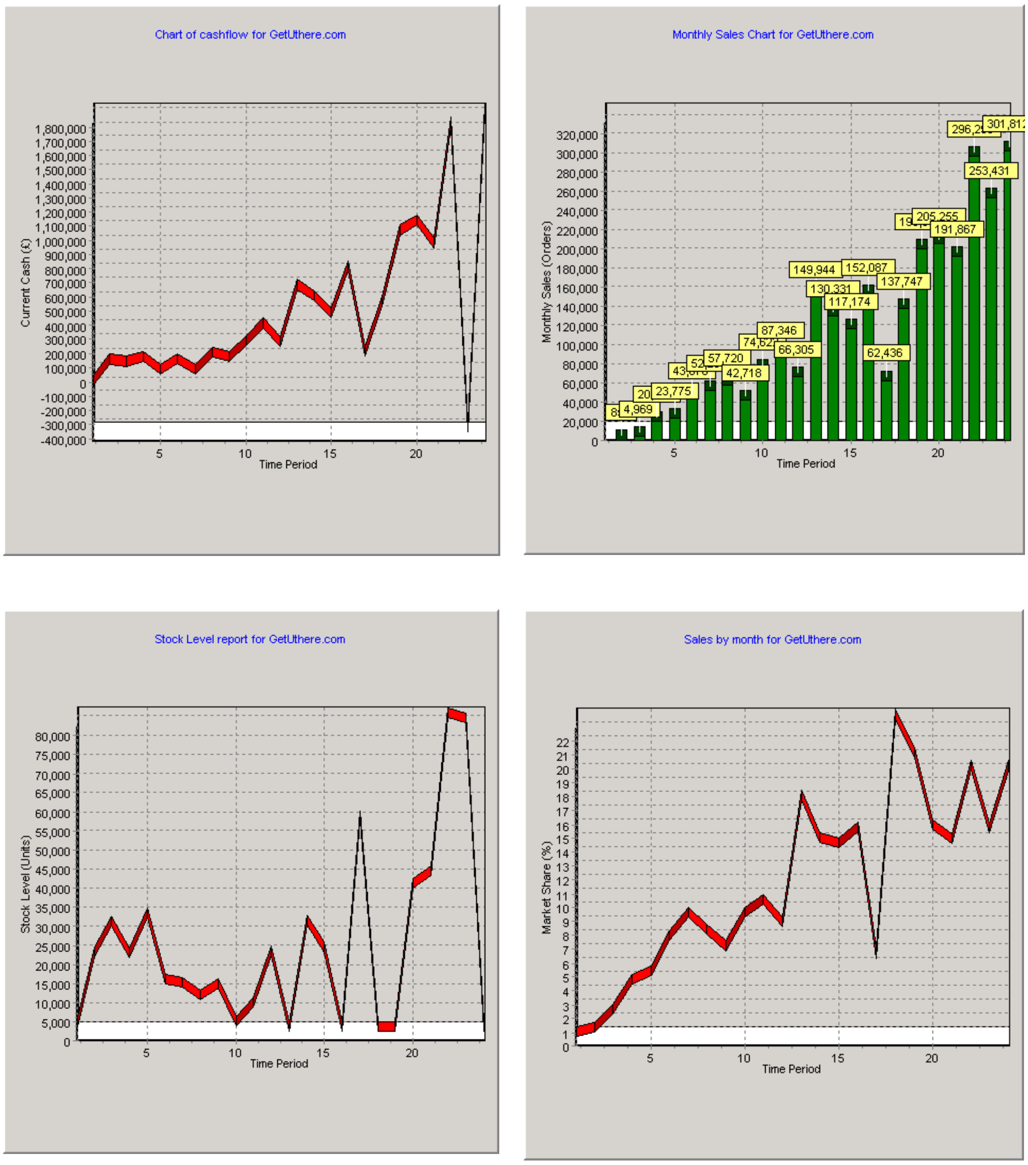


Figure 6.6: Performance charts for student #1

Reasons, other than random events and market fluctuations, for the reduced performance for student #8 are clear from the data files which show that their marketing spend was too low and they employed too many staff unnecessarily in the early stages of the simulation. The fact that the student noted these mistakes in their report indicated they had showed reflection on their performance and accounted for additional assessment marks.

The main reasons for the higher assessment marks for student #1 are due to the quality of the report they produced and the fact that their decision making was effective and timely. They responded to events well and did not make any unnecessary adjustments from their business plan unlike student #8.

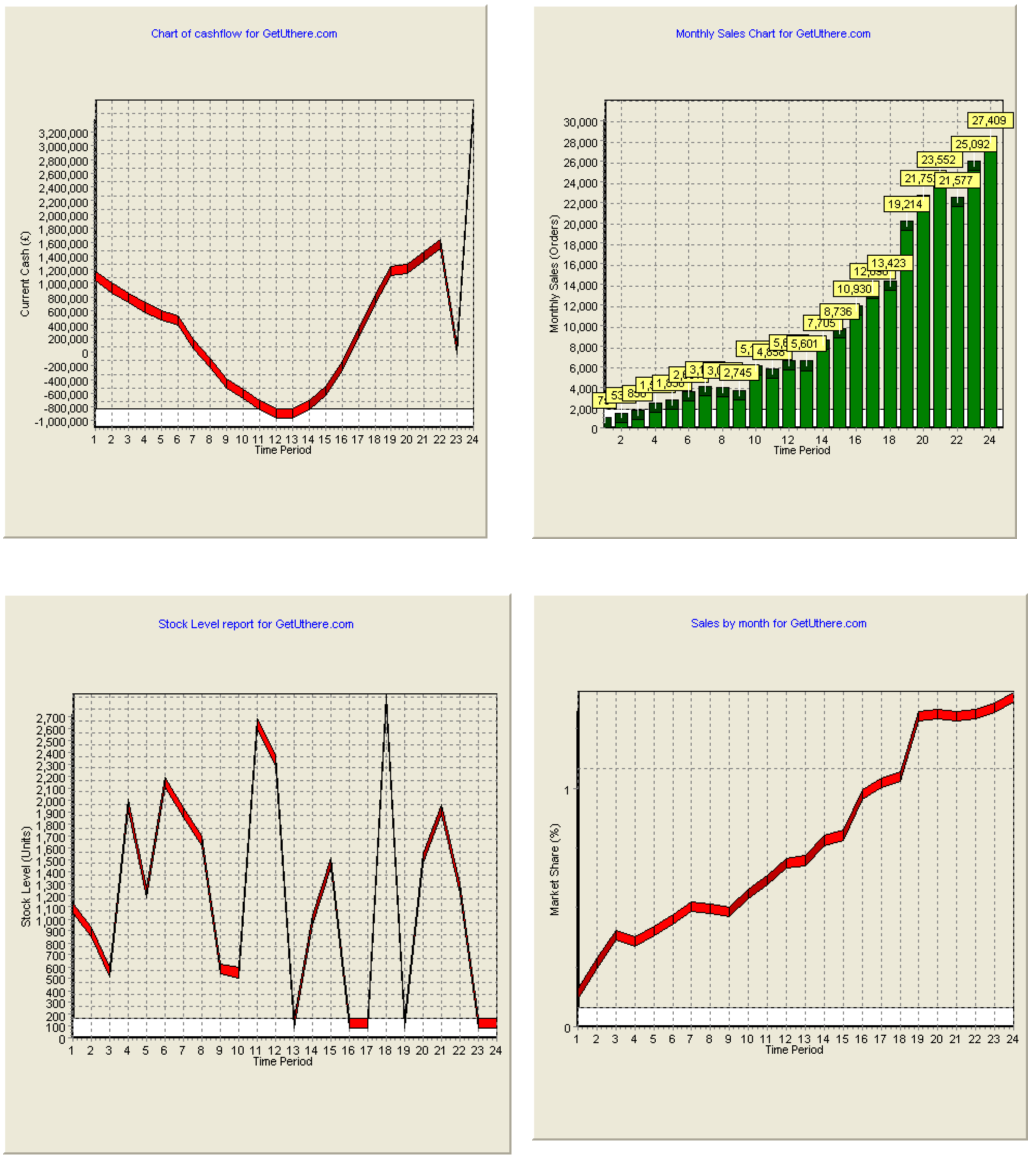


Figure 6.7: Performance charts for student #8

6.4.3 Case #3

This example looks at two students (ID 2 and ID 9) from academic year 2005/2006. Both students were in the group running the TerrainMaster simulation. This business model shows the flexibility of BizSim as they had an unusual situation where the company proposed had an agreement with the military in which large purchases would be made at fixed intervals during the simulated periods. Figure 6.8 show the monthly sales for both students with the large spikes at months 3, 6, 9 and 18 representing military purchases.

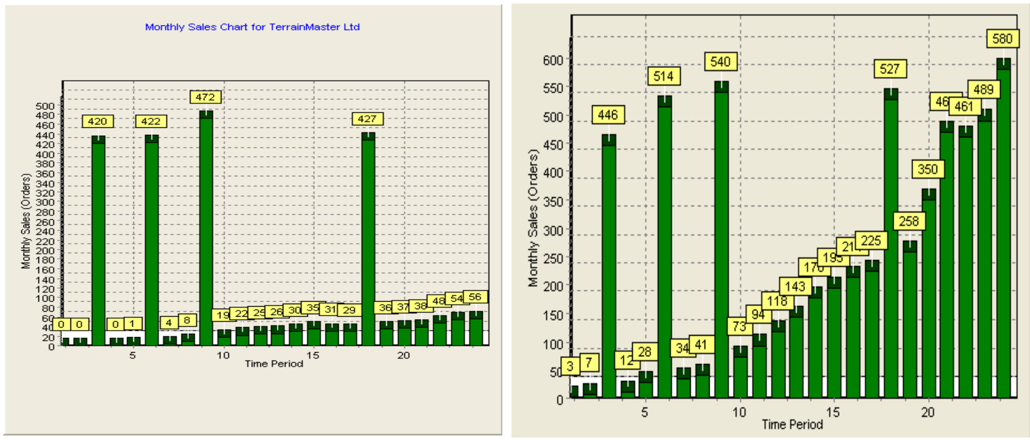


Figure 6.8: Monthly sales chart showing military purchases as large spikes for students #2 and #9

It is clear from figure 6.8 that student #9 was more effective at generating sales and the difference in profitability arising from this is shown in figure 6.8. Student 2 shows a flat level of sales throughout the simulation. It is clear from the simulation data and the student's own admission in their report that they relied on the military sales and did not concentrate on growing the civilian side of the business.

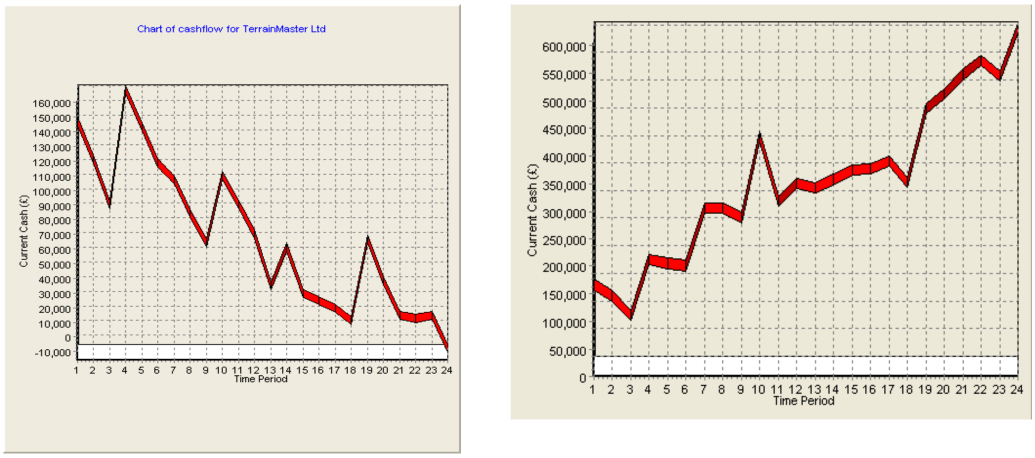


Figure 6.9: Cashflow charts for students #2 and #9 showing the large differences in performance between the two students

The difference in performance between the students is clearly shown in figure 6.9 with the steady decline in company cashflow evident throughout the simulation for student #2 and the opposite for student #9.

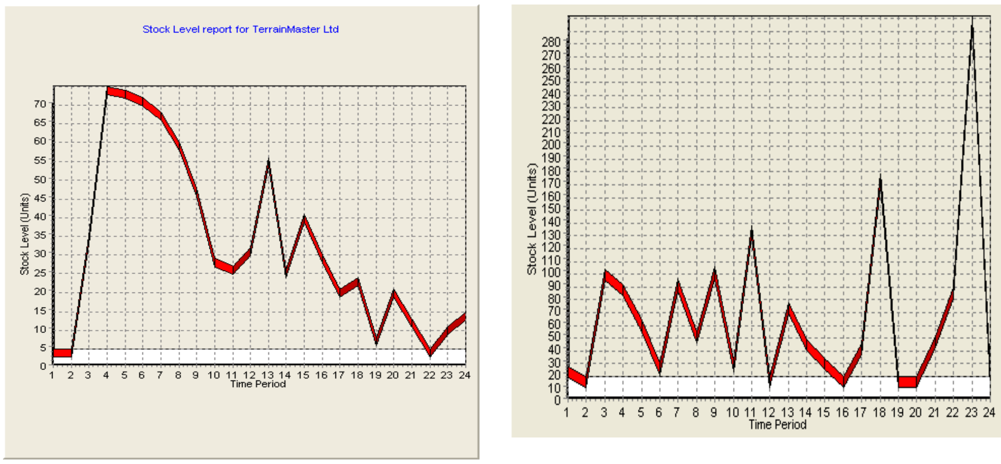


Figure 6.10: Comparison of stock management between the two players (student #2 left, student #9 right)

It is clear from figure 6.10, that student #2 did not manage their stock as well as student #9. Student #2 purchased too much stock initially, heavily reducing their cashflow, and then did not generate enough sales considering the amount of stock purchased; Student #9 maintains a lower level of stock and tries to purchase only the stock that will be needed. This seems a more sensible approach and is borne out by the differences in their performance.

It is important to note that the exercise was a useful experience for both players and student #2 was aware of their mistakes and poor performance as they state in their conclusions

> *So, if better decision making, particularly where marketing budget is concerned, had been employed then the company would probably have been able to move into 2009 quite comfortably. A bigger market share would have been gained, more revenue could have been gained through interest on the deposit account, and selling price could have reflected the increase in manufacturing price. It is fair to say that there were several pieces of misfortune along the way, namely a competitive product appearing in the market so early on, the military sales ending so abruptly, the bad reviews received in the first half of 2008 and the increase in manufacturing price. However such things must be partially expected and compensated for. It would be wrong to assign any blame for the company's failings on misfortune alone.*

6.5 Conclusions and lessons learnt for further research

The experience of running the STaB and MPT modules was invaluable to this research programme. Feedback from students showed that they found the experience useful and gave them an opportunity to reflect on the business plans produced during the teaching module that would not have been possible in any other way.

The BizSim simulation was effective in achieving the aims of the work outlined and its ability to model the wide variety of business and markets proposed by students was impressive. Students responded that they would like additional reporting and control functionality within the simulation and this could be possibly achieved given a longer time for the modelling of their simulations but is not practical within the temporal constraints that existed in this teaching module.

The change to the MPT module in the third year made the production of the simulations much easier due to the increase in contact time with the student groups and the much earlier access to their business plans. This enabled the production of more complex simulation models for the students and the inclusion of a greater range and variety of events within the simulation.

Analysis of individual student performance showed how game performance is often linked to their ability to produce a report of good quality. Evidence was shown that even those students who did not perform as well as others learnt from their experiences and understood many of the reasons why their simulation did not produce their expected results.

Some other important lessons learnt for the overall research project were:

- Unsupervised learning is difficult to assess due to the lack of control over the learning experience
- Unsupervised learning is problematic due to the lack of interaction between teaching staff and students during the use of the simulation game.
- Additional data on learner activity and time spent would have been beneficial in the assessment of learning
- With only a single play-through of the game by each student it is difficult to assess individual improvement and learning.
- Tailoring the simulation game to a scenario well known and familiar to the students seems to increase their engagement with the learning experience. This was seen in the comparison between the use of BizSim and SESAMEE.

7. Preliminary trials and validation exercises

In this chapter a number of case studies and small trials are described. They do not form a major element of the research programme such as the work described in chapters 6 and 8 but do represent significant steps in refining the overall research methodology and developing simulation games for the purposes of teaching. The trials and case studies are described in order of their operation.

7.1 Early case studies using the Muck game for teaching construction management to students

This section covers a series of early uses of the revised Muck Game (as described in chapter 5) for teaching purposes. These trials were carried out with postgraduate (MSc) students in the Netherlands and with undergraduate students at the University of Nottingham. Both trials used the Muck game prior to the completion of many of the updates and improvements described in chapter 5 (section 5.3.4). In fact, some of the updates and improvements and updates were developed from feedback from these trials hence the inclusion of details of these case studies in this thesis.

Both of the trials described in this section were performed before the start of the research work which this thesis describes. The Author was not directly involved in either of these trials.

7.1.1 Case Study 1 - University of Twente (Netherlands) Trial

It was agreed with colleagues at the University of Twente in the Netherlands to employ the Muck Game for the teaching of aspects of construction management to MSc students. The teaching was carried out in the academic year 2000 / 2001 prior to the development of the MCG Umpire Tool and many of the other changes detailed in chapter 5 (sections 5.3.4 and 5.5). The teaching was carried out with the Muck Game installed on a number of classroom PCs and the game was used in supervised teaching sessions with members of academic staff present at all times. It is important to note that, despite being run in the Netherlands, the game was not translated into Dutch and all the lectures were delivered in English. A description of some of the main points of the game was reported in a journal paper by Al Jibouri and Mawdesley (Al-Jibouri & Mawdesley, 2001) and can be summarised as follows:

The game was part of a generally lecture-based course. Participants worked in small groups (2, 3 or 4). Groups were both necessary, because of the large number in the class, and beneficial because they encouraged discussion and peer learning.

Before starting work on the project, each group was required to produce a programme of work, a financial plan and a proposed control method. These had to be presented to the main company board.

In every case, it was observed that the students were optimistic in their view of the project. The plans showed that they expected the plant to work at optimum output, that there would be no effect of team working, that the plant fleets would always be balanced, that no uncertain events would happen and that control would hardly be necessary. Students were prepared to defend their view of the project even when questioned. They had analysed the data provided and were convinced that they had the ‘correct’ solution.

The agreed plan was input to the system before work on the dam commenced. Each group was then able to ‘run the game’ (or work on their own project) independently but had to report to the group board as agreed at the briefing.

The game monitored progress against this plan and attempted to make suggestions as to the need to re-plan. If re-planning were done, the system monitored against both the original plan and the most up-to-date plan available.

Participants very quickly realised the optimism of their original plan and took some form of control action. In almost all cases, this involved trying to build the plan at the planned rate and ignoring all other aspects (finance, quality, safety and the environment).

At the end of the project, each group was asked to report to the management board of the company to explain its performance. This ensured that the students thought carefully about their decisions.

Student feedback was also sought through a questionnaire. The responses to one specific question are provided in table 7.1.

The main points reported by the students include:

- The difference between theory and practice
- The importance of obtaining realistic rather than optimistic data
- The importance of control
- The need for planning and control even when faced with an uncertain world

What if anything did you learn from the game, which could not have been learned more easily from traditional lectures? Please give reasons for your statement.
Theory and practice are very different. Need good memory.
You see the results of your decisions very quickly after you make them. Instead of talking, it is <u>doing</u>.
The plant suppliers use very optimistic output rates for their machinery.
My capability to plan and react to the real time actions. The fact that theory isn't always the same as practice.
It is always better to learn from practical situations rather than just to hear someone talking about it.
Practical learning situations are more effective. This game shows that nothing can be planned and controlled exactly.
The control part. Especially unexpected events.
Making an initial plan and finding out it has to be changed.
You can plan in detail but in reality it is always different.
You shouldn't trust the manufacturer information on machine production. Decision making in actual life is more than good planning.
The original planning is never the best planning, because it is not known what the factors like the plant performance are in real life.
You can't always trust the numbers given by a manufacturer of trucks (example) and other information.
I don't trust manufacturers (actual performance very low).
The interaction between many variables; and how to react to changes etc.
Risks involved in projects especially information by manufactures, which you are learning by your own mistakes during the project. Mistakes are "useful".
The numbers given by the manufacturers are not reliable.
Seeing things go wrong much more than you'd expect. Being able to respond to situations.
I learned about the difference between theory and practice.

Table 7.1: Student's Comments on the teaching exercise

One student / group commented on the possibility of learning from mistakes. This arose because they realised that the information that was generated by the game showed, for example, how the productivity was affected when the balance of resources was incorrect. Such an analysis enabled the group to determine the relative importance of the various factors affecting the project. It can also be seen that some students are beginning to realise the importance of risk management.

Eleven groups of 3 players were monitored during their playing of the game and the values of the summary measure which they achieved were recorded. It is important to note that the summary measure values obtained in the early trials in Twente were much lower than the values obtained in the Nottingham trials. This reflects the relative simplicity of the game used. Thus, whilst the values can be used to compare performance between students in Twente, they cannot be used to compare Twente students with Nottingham students. The average result of the groups over time is shown in figure 7.1.

Several points can be made from these results. Firstly, the game was made particularly easy at the start as the weather was set to have little uncertainty and consequently had a minimal effect on the progress of the work. This is reflected in the general level and reduction in the summary score over the first few weeks of the project. Players perhaps used this initial period to understand the effects of control actions.

As the game progressed, the uncertainties inherent in the game increased. This is caused by many factors such as the equipment affecting the haul roads and the weather changing as a different period of year was reached. At this stage, all players experienced a considerable amount of difficulty controlling their project to plan as can be seen by the marked increase in summary measure.

However, players generally learned how to control the situation and the summary measure decreased in most cases. By the end of the project, the work could be considered to be in control although all were some considerable distance from their planned position. (The increase in measure towards the end of the project is caused by some groups going over their allowed duration and incurring liquidated damages costs)

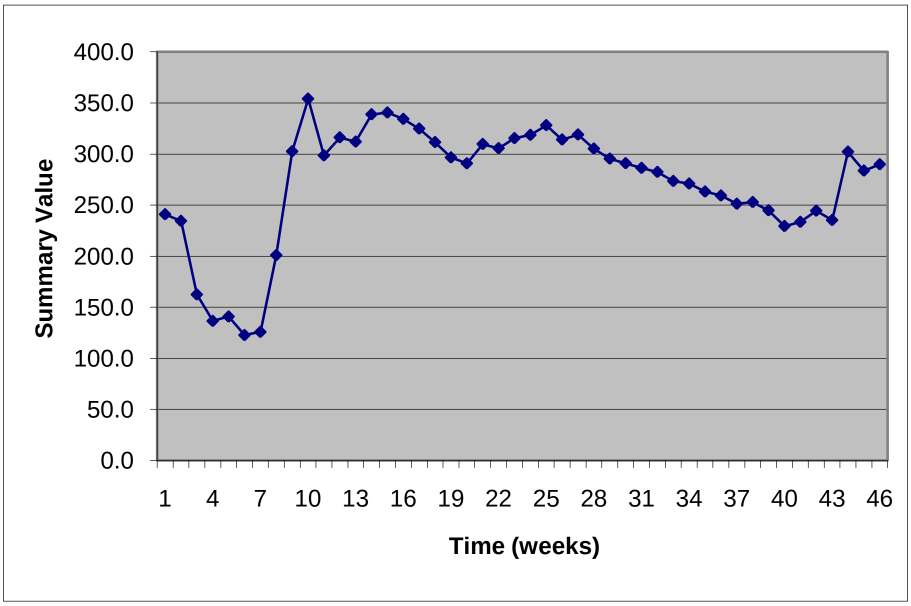


Figure 7.1: Average performance of groups (from Al-Jibouri & Mawdesley, 2001)

Although this graph indicates a general improvement, the performance of the individual groups is not so clear. This is shown in figure 7.2.

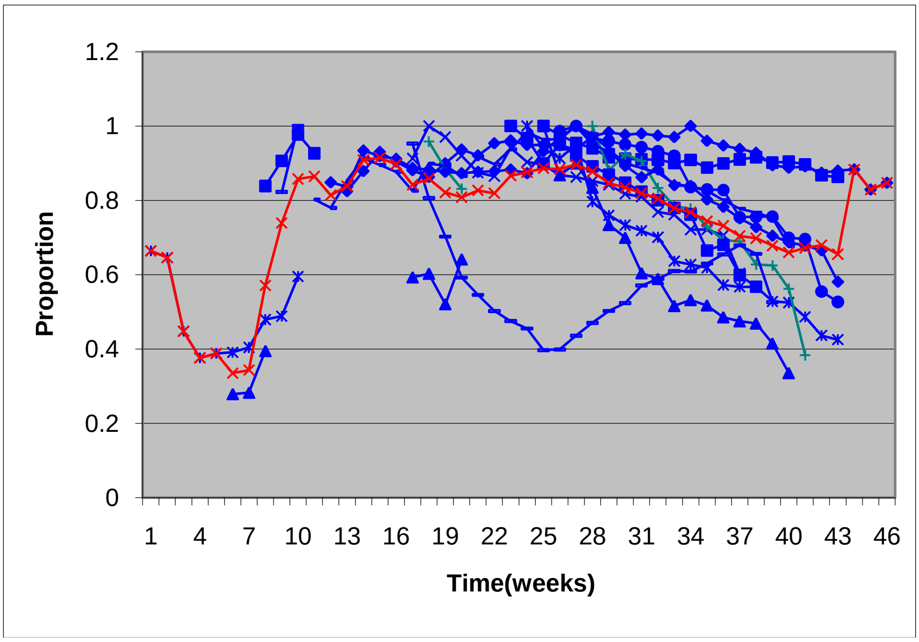


Figure 7.2: Performance of groups relative to their own worst measure value (from Al-Jibouri & Mawdesley, 2001)

In this figure, the performance of individual groups relative to their own maximum summary figure is shown. From this it can be seen that some groups performed much better than others. The worst groups were still achieving summary measure values near their maximum 75% of the way through the project indicating that they were having great difficulty controlling their performance. The best groups, by contrast, were able to improve their performance consistently throughout the last half of the project. This experience with the game provided valuable information for this research. Particular points of interest are:

- The game was very easy in the initial phases meaning that the students could develop an understanding of the playing process but was too easy to maintain the interest and challenge beyond the first run through.
- Academic staff were only able to monitor the students play by being present at all times.
- The game was run in English for people whose native language was Dutch. This caused slight resistance at the start of the project.
- The project was of a type that the students did not recognise as being one that ever happened in the Netherlands. This, for the weaker students, detracted from the exercise.

7.1.2 Case Study 2 – University of Nottingham/Carillion plc

Carillion, one of the UK's leading construction companies, approached the University with a suggestion that they sponsor the Muck Game jointly as a project management teaching exercise for the students and as a recruitment exercise for the company. The two organisations had long standing links with the School of Civil Engineering at the University of Nottingham with Carillion staff being regular members of industrial panels for the school. Both institutions have been involved in a wide range of projects over a number of years. The specific aim of the project as described in the original documentation is as follows:

> *"To give an insight into project management with the chance to test an individual's knowledge and ability within this field of expertise. To also give students the opportunity to find out more about project management and construction from one of the UK's leading construction to service companies – Carillion"*

Carillion had long held the view that graduate engineers in general, though often technically excellent, tended to lack in areas related to general business and management skills. This included things such as communicating ideas effectively, team working and being able to apply sound judgment with only limited viewpoint of the problem. Their enthusiasm for the project stemmed from the fact that the Muck Game's use in teaching is aimed at specifically addressing those elements of learning. Figure 7.3 is a scan of a press clipping from the University Of Nottingham School Of Civil Engineering's in-house magazine, *Connections*, describing the exercise.

Carillion invited students interested in joining them to attend a course run one evening per week over four weeks in February and March 2001. The course consisted partly of lectures and partly of the game. The lectures were on topics which the company thought were important to their operation and included decision making, risk management, team building, communication and project planning and control. All the lectures were given by senior people from the company and were illustrated using their own real projects and features from the game. A timetable for the project is shown in Table 7.2.

Connections

A collaboration between the University of Nottingham and Carillion plc

carillion

"The School of Civil Engineering at the University of Nottingham has enjoyed close links with Carillion plc for a number of years. The collaboration has covered student sponsorship and work placements; training courses staged in the company; graduate recruitment; guest lectures; social events; an annual prize for the best student performance in construction management topics on the degree course; and significant co-operation on projects, research initiatives and software development. The latest venture is the Dam Game which ran for the first time in 2001."

Dam Construction Game

The Dam build project management simulation game was successfully completed after a well fought presentation competition resulted in 'Beaver Construction' winning the £100 presentation prize but 'Diablo' taking the £450 team prize. This concluded a highly successful pilot scheme between Carillion and Nottingham University to, not only help sell the Construction Industry, but also show students some of the excitement and challenges of managing a construction project.

The game involves teams of students becoming project managers to construct a virtual dam. Each team takes responsibility for the equipment used, and has to carefully plan the works and consider the project finances. During the simulation, decisions made by the teams effect safety, the environment and quality on the project. Students control progress using state of the art techniques and present their successes (!) to a Carillion 'board of directors'.

The budding Project Managers

Colin S Mick Niall Quentin Colin B

The game was well received by the 30 civil engineering students who took part and it is planned that next year the game will be offered to other faculty disciplines. Carillion will be taking on 4 summer placements from Nottingham this year.

Presenting to the 'board'

Thanks goes out to Dr Michael Mawdesley (School of Civil Engineering at Nottingham University) without whom the game could not have been invented and to the 'Carillion Board' comprising - Quentin Leiper (Director for Engineering and the Environment), Colin Brady (Project Manager on the Nottingham tram project), Colin Stevens (Chief Planner on the Nottingham tram project) and Niall O'Hea (Graduate Development Manager) without whom the food and drink could not have been consumed!

Figure 7.3: Description of the teaching exercise from University of Nottingham School of Civil Enginering's in-house magazine.

The participants were observed at all stages of the game from their team building through the decision making and planning to the completion of the project. When the project was finished, all groups were asked to present their project to senior company personnel.

The company were very pleased with the game especially in the way that it demonstrated the complexity of real projects and the need to consider so many apparently unrelated topics in order to manage it. They commented on how well it enabled them to observe the behaviour of the participants in a near-realistic environment.

The participants enjoyed the experience and found it rewarding not only because many were offered employment but also because the company offered a first prize of £400 and a second prize of £100! (The choice of prize winners was made by the company and not based solely on the amount of profit made).

20/02/01	Introduction to the event by Carillion (Niall O'Hea) and to the game by Nottingham University (Dr M J Mawdesley)	Groups given details of the game and shown how to play the basic format
27/02/01	Presentation on project management by Quentin Leiper (Carillion). Presentation will touch on safety, environmental issues, planning and risk management Issue of Carillion requirements – Each project management group will be issued with specific orders from the company	Groups will be encouraged to interact with Quentin to find out as much as possible about project management in the real world. Groups will have to re-plan their strategy to take account of Carillion's company strategy. There will be 5 different scenarios.
05/03/01	Run Project – All groups will run the project simultaneously	Groups will be given one opportunity to run the game with all real life variances.
12/03/01	Presentation – Each group will present to the Carillion board on the success of their project. They should be expected to answer questions. The prize shall be awarded on: Final score from the game 60% Presentation + question session 40%	The group can present using any format. The presentation should be no longer than 10 minutes and should cover: What was required? How was the work planned? What happened? How did the project team react to unexpected events?

Table 7.2: Project timetable

7.2 Case Study 2 – Initial trial of the SubCon simulation game

The SubCon game, as described in section 4.2, was intended to teach key aspects and implications of the use of subcontracting in the construction industry. The game was tested with a group of postgraduate research students over a period of two weeks in 2004. The work described in this section was performed solely by the Author with the support and assistance of the project supervisor.

7.2.1 Construction project simulated

Due to the ability of the SubCon game to simulate any project it was also necessary to select an appropriate construction project for the purposes of the trial. It was decided to use an example project involving the construction of a Tank Farm. This project had been used over a number of years in the teaching of planning and activity networks to undergraduates at the university. The project was therefore clearly defined, easy to adapt to a format suitable for SubCon and was well known to the trial participants. Their existing knowledge of the project was to prove beneficial in reducing the difficulties of running the trial.

The project consists of the construction of six underground reinforced concrete tanks, the pipework to connect them to the client's main pipeline, the offices and pumphouse and associated roads and sewage facilities.

The tanks are built in-situ of reinforced concrete with a liner fitted by a specialist sub-contractor and the roofs constructed of precast concrete beams. The pipeline is hung in a precast concrete culvert with a precast concrete lid.

The site boundaries are as shown on the drawing in Figure 7.4.

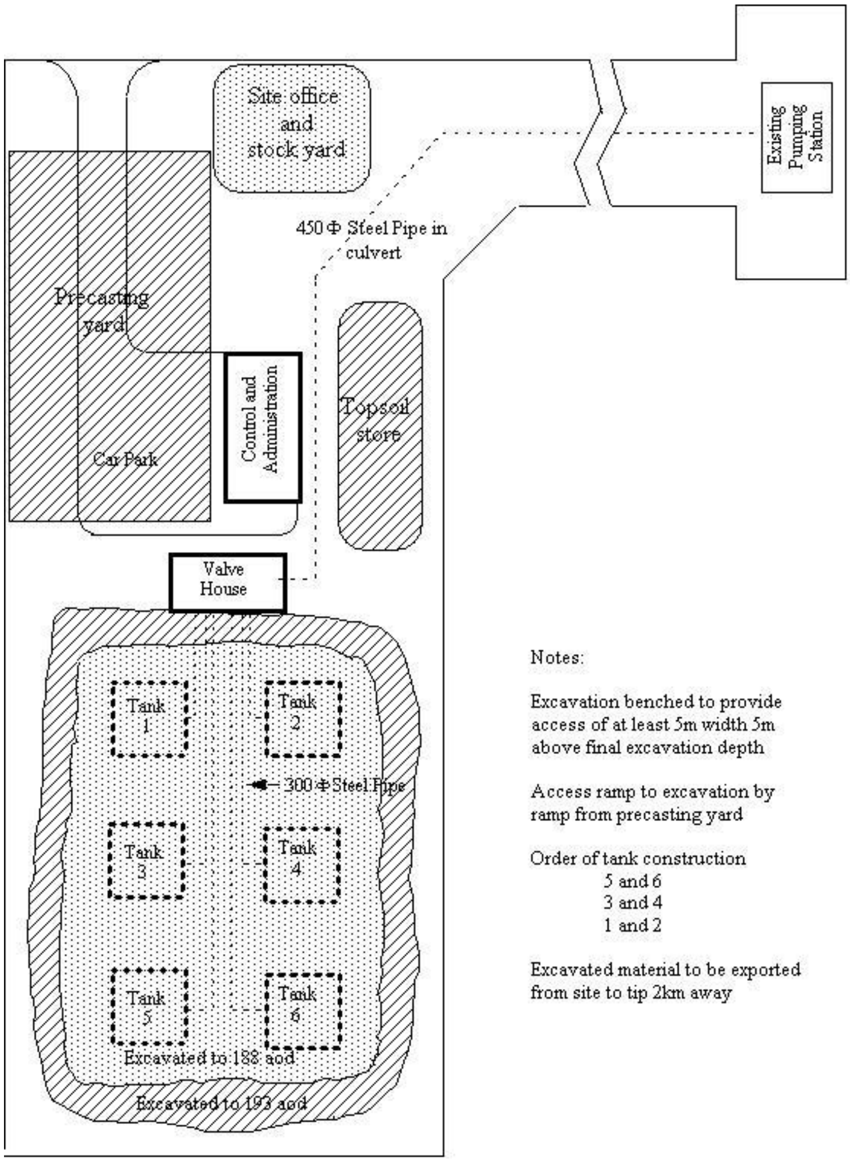


Figure 7.4: Diagram of Tingham tank farm project site

The simulated Tingham Tank Farm project was initially broken down into 77 activities (Table 7.3) requiring the collaboration of the 8 contractors listed in Table 7.4. The activities have a number of properties associated with them. These include activity value and difficulty but have not been included in Table 7.3 as they are not directly relevant to the discussion here.

Number	Activity Name	Number	
1	Start	40	Backfill Tanks 2/3
2	Set up site	41	Excavate tank 3/3
3	Install Batching plant	42	Base Blinding 3/3
4	Construct precast yard	43	Base formwork 3/3
5	Precast roof 1/3	44	Base reinforcement 3/3
6	Precast roof 2/3	45	Base concrete 3/3
7	Precast roof 3/3	46	Base Curing 3/3
8	Precast culvert 1/3	47	Base strip formwork 3/3
9	Precast culvert 2/3	48	Tank lining 3/3
10	Precast culvert 3/3	49	Wall formwork 3/3
11	Excavate tank 1/3	50	Wall reinforcement 3/3
12	Pipe connections 1/3	51	Wall concrete 3/3
13	Base Blinding 1/3	52	Wall curing 3/3
14	Base formwork 1/3	53	Wall strip formwork 3/3
15	Base reinforcement 1/3	54	Backfill Tanks 3/3
16	Base concrete 1/3	55	Excavate pipe track 1/3
17	Base Curing 1/3	56	Construct culvert 1/3
18	Base strip formwork 1/3	57	Culvert pipework 1/3
19	Tank lining 1/3	58	Excavate pipe track 2/3
20	Wall formwork 1/3	59	Construct culvert 2/3
21	Wall reinforcement 1/3	60	Culvert pipework 2/3
22	Wall concrete 1/3	61	Excavate pipe track 3/3
23	Wall curing 1/3	62	Construct culvert 3/3
24	Wall strip formwork 1/3	63	Culvert pipework 3/3
25	Backfill Tanks 1/3	64	Pipe connections 3/3
26	Excavate tank 2/3	65	Tank roofs 1/3
27	Pipe connections 2/3	66	Tank roofs 2/3
28	Base Blinding 2/3	67	Tank roofs 3/3
29	Base formwork 2/3	68	Offices and roads topsoil strip
30	Base reinforcement 2/3	69	Excavate roadworks
31	Base concrete 2/3	70	Excavate office site
32	Base Curing 2/3	71	Site drainage
33	Base strip formwork 2/3	72	Construct roads
34	Tank lining 2/3	73	Construct prefab office
35	Wall formwork 2/3	74	Sewers
36	Wall reinforcement 2/3	75	Sewage works
37	Wall concrete 2/3	76	Landscaping
38	Wall curing 2/3	77	Finishes
39	Wall strip formwork 2/3		

Table 7.3: Table of activities within the Tingham tank farm project

The activity network for the project is shown in appendix C and is not included here due to its size.

7.2.2 Method

As stated in chapter 4, the game was initially planned to be a single player simulation game with the system taking the role of the subcontractors and the player taking on the role of the main contractor. During development it was decided that the use of the game as a multiplayer experience was worthy of investigation and the game was designed to run in either single of multiplayer modes. One of the aims of this trial was to investigate the behaviour of human players taking on the role of subcontractors. This could then be utilised in developing the game AI for the subcontractors in the single player version of the game.

For the purposes of the trial, it was decided to run the game in multiplayer form with trial participants taking on the roles of the individual contractors within the simulation. To this end, each contractor's aims and objectives in relation to the simulated project were defined and given to the participants in order for them make appropriate decisions during the trial. The specific roles and their descriptions are shown in Table 7.4.

The trial involved 4 postgraduate research students. One student took on the role of the main contractor and in-house subcontractor. The three other students were given 2 subcontractors each to manage with their own specific goals and constraints regarding their involvement with the project.

Each simulated week of the project, the players assign their resources (in terms of work gangs). The choice of assignments is determined by each player though the main contractor can request that activities be carried out and determines payment to subcontractors. Each player assigns resources according to the needs of the project, the request of the main contractor and their own specific aims and objectives which may or may not conflict with the needs of the project and the main contractor.

Each player has full information on their own resources including their cost, skills and productivity rates for each skill. Players are not aware of the resources available to other players or their properties. This meant that players were able to tell other players as much or as little as they wished in regard to the availability and ability of the resources they allocated. Players could choose to deceive or be completely open with other players in order to achieve their own objectives.

Player resource allocations were done on specifically designed forms for the purposes of this trial. These were then fed into the simulation by the researcher and the simulation was advanced. Results were then provided to the players and the sequence began again. This was repeated until the simulated project was completed.

Contractor	Description of role and aims for the simulated project
Main Contractor	This project represents a new are of work for us. It is the first project for the client. We hope to get a lot more work from the client and therefore we really must finish by day 340. There is only room for one crane on site. Assigning the crane to jobs efficiently is critical to the projects success. Profit is less important than time but we must not make a loss.
General subcontractor (in-house)	Getting the project finished on time and within budget is our primary concern. We must aid the project manager in ensuring that things run as smoothly as is possible. However, we must also ensure that we at least break even in terms in project spend vs. earnings. If men standing idle will help persuade other subcontractors to deploy their resources then it must be tolerated.
Joinery subcontractor	We would like to cultivate this main contractor and eventually enter into a long term relationship with him. All the formwork is in large panels which need a crane for lifting.
Specialist Lining subcontractor	We have agreed continuous working for our gangs but suspect that this will not be possible. Be prepared to negotiate a higher rate of compensation for non-continuous working. It would be much better if we were warned of when our gangs would not be used.
Earthworks subcontractor	We would like to get in and out of the project as quickly as possible. Idle time costs a lot of money. Avoid it at all costs. If there is any, make sure to claim money for it from the main contractor. We are unsure of the ground conditions and would like to ensure that we are not charged if our work overruns the predicted durations
Pipe-fitting subcontractor	We consider ourselves to be the best pipefitters in the country. The quality of our work is excellent. If clients/contractors think we work too slowly, it is they who are mistaken. We expect be paid on time and in full. If our gangs are forced to stand idle, we expect compensation.
Precasting subcontractor	We would like constant workload for our company. We are very concerned to get all the money we can from the main contractor. Profit is our sole motivation in terms of this project. Do not have work gangs standing idle.
Steel-fixing subcontractor	We have over-committed ourselves project wise at the current time. Try to use as few gangs as possible without noticeably annoying the main contractor. If high resource levels are required then this must be matched by high profits.

Table 7.4: Contractors in the trial and their objectives

7.2.3 Results

The primary findings from the multiplayer trial of the SubCon game were in relation to the nature and length of the gameplay when used in this role. Prior to the trial, the majority of the testing carried out on the game was in single player mode. The multiplayer mode was only tested briefly to ensure that it worked subject to requirements.

The duration of the game when played with multiple players was found to increase dramatically due to the interaction between players and the group decision making occurring. It is thought that the time required could have been reduced by providing greater explanation of the workings of the game in advance of commencing the game. The use of a small test project with fewer contractors to introduce the players to the workings of the simulation on a more easily manageable project may also have been an effective method for using the SubCon game in any future trials.

Overall, the length of trial was found to be excessive and would have led to frustration if attempting to use the simulation game in this way with actual students.

This was an important finding if the game was to be used in multiplayer mode subsequently.

The game's functionality was also found to be a limitation when playing with multiple players. The only real option for subcontractors was in the allocation of work gangs and equipment. The agency of each player (see chapter 3) was low, even for the main contractor. This would significantly reduce a student's engagement with the game though it may well be representative of the reality of the subcontracting process. Some additional functionality for each contractor was devised in light of the trial which could increase player control of the game (e.g. modification and creation of work gangs and time scheduling of workgangs) but these would still not significantly increase their overall agency.

During the trial, additional functionality was added to enable the main contractor to be able to make discretionary payments to subcontractors at the request of the players. This enabled greater flexibility in terms of negotiation between the main contractor and subcontractors.

An important finding of this trial was in relation to the behaviour of the players. It was found that the players tended to cooperate and diverge from their specified role as play progressed. They seemed to forget the needs of their individual companies and act for the benefit of the project as a whole. It is thought that the principal reasons for this behaviour were:

- The group of trial subjects were all colleagues who worked closely together and had a natural tendency to cooperate
- Since the trial subjects were not be assessed on their performance there was no incentive to stick closely to the roles provided
- The players tended to forget their individual aims as they become engaged with the simulated project
- The importance of sticking to their defined roles and aims was not made fully clear to the test subjects

It is thought that this behaviour would not be repeated to this extent if the game was being used with actual students. Assessing students in relation to their performance to role would probably have made a significant change to their behaviour. Playing the game with a randomly chosen group of players without any strong existing relationships would also be likely to have an effect on the degree of cooperation and acting to role.

7.2.4 Conclusions

Although the trialling of the SubCon game was quite limited in comparison to BizSim and the Muck and Canal games, a number of conclusions can be drawn in terms of any future development of the simulation as a multiplayer game:

- The number of individual contractors should be more limited in order to maintain the flow of gameplay. The seven different roles involved in the trial created problems and their individual involvement at differing points in the simulated project meant that some players would be uninvolved for large periods of the simulation. In the trial, players took a number of roles to avoid this issue but this created additional difficulties with players becoming confused as to their aims across different roles played. The subcontractors involved in the trial project were redesigned to reduce the overall number of players and increased each player's role throughout the simulation. These revised contractor profiles are shown in table 7.5.
- Player control or agency over the simulation is too limited in the trial version of the simulation game. A number of enhancements to the gameplay and user interface were proposed to reduce this problem. These include the ability for players to create and edit their individual work-gangs, for players to be able to recruit additional resources (staff and equipment), the ability to make changes to resource allocations more frequently (only weekly allocations allowed in the trial version) and for players to be able to choose from different working methods for activities.
- The SubCon game may operate more effectively as a turn-based game when using multiple players. This could be achieved through a web based interface or by playing the game via email. Each subcontractor could make their resource allocations and then submit them to the main contractor by a specified deadline. The main contractor could then advance the simulation and results would be posted to all players in relation to their involvement.
- The introduction of additional content will be required to make the game more engaging. For example, the generation of random events linked to player activity such as health and safety incidents or work quality issues

The revised contractor structure shown in table 7.5 reduces the problem of having too many roles with too little work though there are still major differences in the involvement of subcontractors. SC1 is involved mainly at the beginning and the end of the project with some limited (yet critical) involvement in the curing of the concrete mid project. SC2 has only 3 gangs and their work is relatively unaffected by the other subcontractors except for their craneage requirements. They are involved throughout the project but only in a handful of very long duration activities. SC3 & SC4 have limited involvement and only a few gangs though delays to their activities can disrupt the project badly. SC3 will be very lucky to make any profit. SC4 is being overpaid in comparison (they are specialist and can name their price). SC5 is performing the largest number of activities though they are mostly of a short duration. They are mainly very linear activities, of which, many lie on the critical path.

ID	Contractor	Activities
MC	YOR Construction Ltd (Main Contractor)	Overall management of the project. Control of shared resources (e.g. cranes)
SC1	YOR Construction Ltd (In-house general construction subcontractor)	General Construction work, Curing concrete, Drainage work, Building of simple structures
SC2	Barr Precasting UK plc	General Construction work(setting up precasting yard), Precasting concrete
SC3	Tingham Earthmovers Ltd	Excavating, Backfilling, Landscaping work
SC4	Roach Industrial Ltd	Installation of specialist lining material, Installation of pipework
SC5	City Concrete Contractors Ltd	Installing formwork, fixing reinforcement, Pouring concrete, Stripping formwork, Installation of precast concrete

Table 7.5: Revised list of contractors and their roles

In terms of further development of the *SubCon* game as a single player experience with the player taking control of the main contractor, a number of findings from the multiplayer trial may be useful:

- Feedback from game controlled subcontractors would need to be carefully designed to ensure that the player understands the reasons for their behaviour and does not become frustrated by the actions of the subcontractors.
- The player would need greater ability to influence the autonomy of the subcontractor’s behaviour in order to make the simulation game more engaging. This would reduce the fidelity of the simulation somewhat but would be necessary to avoid player frustration. The degree of influence would need to be carefully balanced to ensure that realism is not excessively compromised.
- Allowing the player to select from a range of subcontractors at the start of the simulation would seem to be an effective way of increasing the interactivity of the game. It would also allow the player to examine the impact of their decisions on simulated performance. Each subcontractor would be classified by a range of properties such as cost, quality of their work, speed of work, number of resources available, current workload and safety records.

7.3 Case Study 3 - Using the Muck Game for group-based learning at Curtin University, Australia

Colleagues at Curtin University of Technology in Perth, Western Australia proposed to use the Muck Game for teaching their students. A number of meetings were held and a dialogue was established to identify the requirements of the teaching proposed at Curtin, the changes to the Muck game necessary to fulfil their requirements and how the teaching carried out at Curtin could be analysed as part of the PhD research work described in this thesis. All the teaching work and data collection was carried out by colleagues at Curtin University. Technical support and analysis of the data produced was carried out by the author and project supervisor and were important inputs to the overall PhD research programme.

A large amount of the initial developmental work described in chapter 5 was planned and designed prior to and during the operation of this teaching programme. Examples of this include the development of the MCG Umpire Tool, the network based version of the Muck Game and the increased ability to customise the Muck Game simulation. Further development of the muck game and umpire tool arose from feedback from this case study and is discussed in section 7.4.

Case study 3 involves a teaching module which operated at Curtin University over a number of years. The module was aimed at first year engineering students in their first term of undergraduate study. It was not limited to civil engineering students and involved students at the university from all engineering disciplines. It was intended to give the students an engaging and alternative view of managing engineering projects from the traditional tell-test approach.

Prior to using the game on the first year common engineering course it was evaluated as a teaching tool by its inclusion as a part of a Civil Projects Economics unit with groups of third year students. Documentation describing this initial trial is shown in appendix D. The methods employed and results from both these exercises are described in a number of publications (Scott et al, 2004; Gribble et al, 2006; Mawdesley et al, 2008).

7.3.1 Method

A key aspect of the teaching module was to introduce students to the concept of working as part of a team and the Muck game was run by groups of 4 or more students. Each group played through the Muck game once in supervised sessions. Each group had to produce and present an initial plan to the teaching staff before commencing the simulation. Group plans and documentation were displayed and updated regularly as part of the teaching process, an example of this is shown in Figure 7.5.

Students ran the simulation under controlled conditions with staff available to monitor their use of the Muck game. The Muck game was run using standard settings but using the rainfall figures for Perth, Western Australia (Table 8.3).

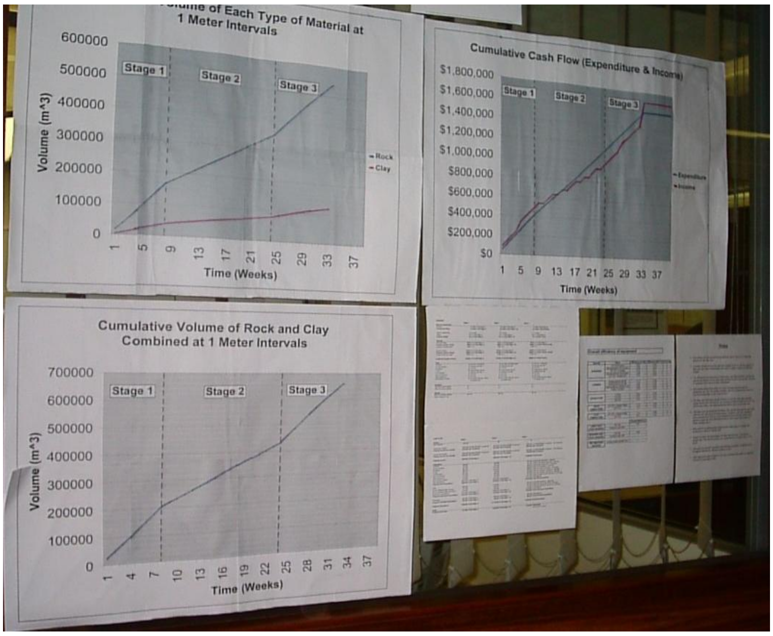


Figure 7.5 : Example of student planing from case study 3

On completion of the exercise students were assessed on their ability to report on the simulated experience both through verbal presentations by each group and individual written reports. Students were also required to complete questionnaires on the experience which were used to evaluate the effectiveness of the teaching module.

7.3.2 Results

Results from the questionnaires used in the initial trial at Curtin are shown in Figure 7.6 & Figure 7.7 for illustrative purposes. Questions involved students assessing their own performance at achieving the learning outcomes for the module. This exercise for the learning outcomes related to fundamental engineering principles in shown in Figure 7.6 and the results for those related to professional practice is shown in Figure 7.7.

Feedback from students was generally positive with the majority of students enjoying the experience. Difficulties and criticisms reported by students were reviewed and changes were made to the Muck game where deemed to be required. An example of this would be in additions to the reporting options available to the player such as the ability for students to be able to review all the in-game messaging that occurred during the simulation. The feedback from this case study was also an important input in the development and evolution of the *Applied Construction Project Management* (ACPM) teaching module that is the focus of chapters 8-10

It shows that the game can be effectively used with students who have more limited experience of engineering and project management and provides a good counterpoint to the work done with experienced and postgraduate students described in the later chapters of this thesis (chapters 8-10).

Figure 7.6 & Figure 7.7 show a positive trend in terms of student assessment of their achievements. The majority of the responses are positive with response 4 (slightly agree) being the dominant response in 8 out of 10 questions shown and being the second most popular response in the remaining two questions (figure 7.6 questions 3 and 5). Neutral responses are the next most frequent response and only a single question receives any strongly negative response (figure 7.7, question 5)

For a more detailed discussion of the teaching exercises at Curtin, Gribble (Gribble et al, 2006) describes the evaluation of the learning experience in greater depth than is relevant here.

Item	
1	I now understand the basic principles of the design/construction process.
2	I could apply basic design/construction principles in other similar representative exercises.
3	I now can use engineering judgement about the quantifiable activities of project delivery.
4	I now can use effectively the "plan-monitor-control" cycle.
5	I have learnt more about how to structure engineering problems into a sequence comprising identification, formulation, solution, and impact.

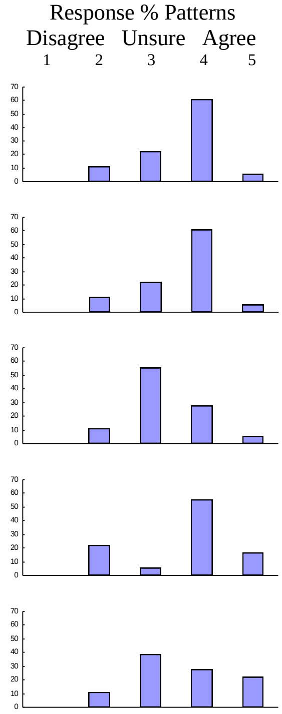


Figure 7.6: Responses from students in terms of engineering aspects of feedback questionnaire

For the later use of the Muck game for teaching first year students at Curtin, the MCG Umpire tool was available and was used to monitor student activity and collect data on their use of the game. The data was collated and analysed as part of this research programme in order to provide a comparison for the data collected during the ACPM module described in chapters 8-10. A full description of the key performance variables used to assess this data is given in section 9.2.

Data for all groups taking the module at Curtin from 2005 is included in the e-appendices along with the original student data files. Overall statistical information for the data collected from Curtin is shown in table 7.6.

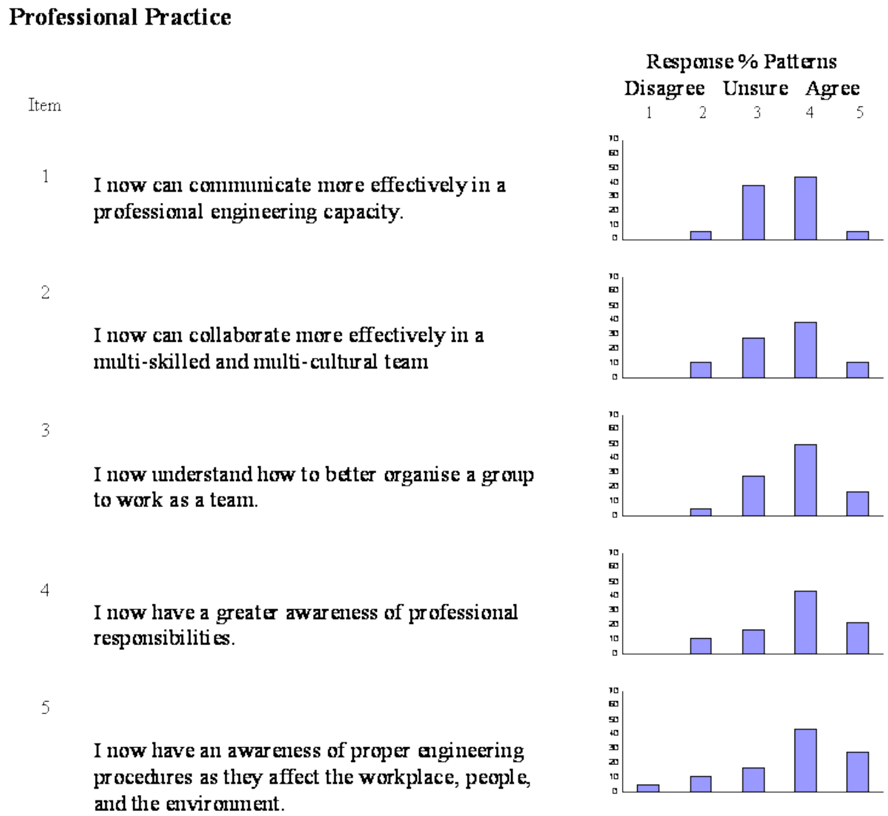


Figure 7.7 : Responses from students in terms of professional practice aspects of feedback questionnaire

Performance figures can be compared with the results obtained under the ACPM module and shown in chapter 9 and the e-appendices. However, it is important to note that many of the changes to the teaching methods between the two modules make direct comparisons misleading. The Curtin students receive much greater feedback on their plans before actually attempting them and their being limited to a single play-through ensures that greater care is taken in their initial attempt. Conversely, the ACPM students have much greater experience in terms of engineering and construction management knowledge and group based working exercises.

Statistic	***Value***	***Statistic***	***Value***
Number of groups	37	Number of games/player	1
Games		**Total mark (%)**	
Number completed	23	Minimum	58
Number played	37	Maximum	90
Completion	62%	Mean	71.6
Time Spent (minutes)		**Project duration (days)**	
Mean	183.67	Mean	160.08
Standard Deviation	101.45	Standard Deviation	68.99
Minimum	0.22	Minimum	0
Maximum	451.78	Maximum	250
Planned – Actual Spend		**Profit**	
Mean	-989,722	Mean	-2,703,006
Standard Deviation	1,006,082	Standard Deviation	10,622,391
Minimum	-4,195,595	Minimum	-66,169,150
Maximum	162,448	Maximum	136,495,

Table 7.6: Overall statistics from Curtin trial (2005 data)

7.4 Summary & key findings from the case studies

This chapter had outlined a range of case studies using simulation games in an educational context. Only the *SubCon* game trial (section 7.2) was directly undertaken as part of this research programme. However, this was closer to an extended testing session than an actual experimental teaching trial. It did however; produce some interesting results leading to a number of modifications to that simulation game and plans for further development in this area. It was also responsible for a number of conclusions and recommendations for further work in terms of the design, development and implementation of simulation games from first principles.

The earlier trials of the Muck game described in section 7.1 provide additional background on its potential as a teaching tool and provided the initial results on its use as a teaching tool. These trials were all carried out prior to the commencement of this research but were to be instrumental in the design and operation of much of the experimental work carried out during this research programme. For example, the feedback from the trial carried out at the University of Twente highlighted the importance of being able to adapt the properties of the simulation game to the audience and the required learning outcomes.

The teaching module at Curtin University (section 7.3) was only indirectly related to this work but results from this study were partially responsible for many of the enhancements to the Muck and Canal games described in chapter 5. Feedback and results from this trial were also helpful inputs to the decision making process for the experimental work carried out under the *Applied Construction Project Management* teaching module at the University of Nottingham (and described in chapters 8-10).

8. *Applied Construction Project Management* (ACPM) – Using Simulation Games as the primary mechanism for teaching aspects of construction management

This and the following chapters describe the primary case study and experimental phase of the research. It forms a major component of the research programme and provided the bulk of the data used to investigate the primary aim and objectives of the work. It details a teaching module, *Applied Construction Project Management (ACPM)*, used at the University of Nottingham in recent years describing the module's design, structure and operation from its first four years of operation. Detailed quantitative data and statistics from this case study are provided in chapter 9. Analysis of individual student data in respect of the research aims is given in chapter 10.

8.1 Aims, Objectives and Learning Outcomes

The ACPM module has a number of aims and objectives both in terms of the learning and research outcomes. The primary aim in terms of learning is to promote student understanding of planning and managing a construction project through the use of simulation. The overall research aim is the principal aim of this research programme as stated in section 1.2, i.e. to quantitatively and qualitatively evaluate the usefulness of simulation games for teaching construction management skills. The learning outcomes of ACPM as specified in the module description are shown in table 8.1.

Many of the learning outcomes described required the students to make repeated attempts at the games since they could not be achieved on a single play through of the games. Outcomes related to transferability of skills in particular required the two games to be available and it is likely that the students would need repeated attempts in order to achieve them. Those outcomes requiring the students to balance various elements (resources, quality, health and safety, etc.) in managing a project would also be very difficult to achieve on a single play through of the games.

Type	Description
Knowledge & Understanding	Mathematical methods appropriate to civil engineering and construction
	Principles of information and communication technology (ICT) appropriate to the practice of civil engineering
	Management and business techniques and practices relevant to civil engineering and construction
	Quality, health, safety and environmental considerations in the context of civil engineering, including professional, legal and ethical responsibilities and risk management
Intellectual Skills	Select and apply mathematical methods in modelling, analysing and solving problems appropriate to civil engineering and construction
	Select and apply scientific and engineering principles to model, analyse and solve problems in civil engineering and construction
	Select and apply appropriate information and communications technology (ICT) to model, analyse and solve problems in civil engineering and construction
	Design and evaluate systems, processes and components in civil engineering and construction to satisfy a need
	Be creative in the planning, execution and reporting of investigations requiring the application of civil engineering knowledge and understanding
	Apply management methods to the evaluation of resource, quality, health, safety, risk and environmental issues associated with civil engineering
Professional / Practical Skills	Generate and process experimental and survey data including an evaluation of the results and their validity
	Use information and communications technology (ICT) including CAD, generic software, simulation systems and software for specific applications
	Produce sketches, drawings and reports
	Design a solution to an engineering problem
	Apply techniques appropriate to civil engineering project management taking into account industrial and commercial constraints
Transferable / Key Skills	Apply mathematical, scientific and engineering techniques in the solution of problems
	Find, sort, manipulate, interpret and present data in a variety of ways using library, internet and other sources of data
	Use general and specialised information and communications technology (ICT) tools
	Use creativity, innovation and critical judgment in solving problems with limited or contradictory information and transfer the solutions as appropriate
	Manage time and resources in personal plans and work to deadlines
	Work independently and in teams in a range of roles

Table 8.1 : Learning outcomes for ACPM module (taken from University of Nottingham catalogue of teaching modules)

8.2 Instructional Design

With the Muck game, Canal variant and Umpire tool in place, The ACPM module was proposed, designed and implemented to employ the games as the sole source of teaching. In order to achieve this, a number of factors were considered and examined during the development phase.

The module was designed with the aims of this research in mind. It is intended to help answer the research objectives posed in chapters 1 (section 1.2) and forms a major element of the overall research methodology described in section 1.4. The instructional design for the module was also informed by the learning needs of the students and by the institutional regulatory framework in place at the University of Nottingham with regard to the design of teaching modules. Knowledge gained in the research phases of the PhD programme, and described in chapters 2 and 3, also played a key role in the instructional design of the ACPM module. The main features of the module as designed are:

- An introductory lecture to describe the module and ensure that students are fully aware of the type of teaching and learning that will be provided and expected of them is the only concession to traditional teaching methods. No other formal lectures are provided
- Only indirect assessment of game performance. Past experience from the work described in chapters 6 and 7 led us to employ no direct assessment of students based on their game performance. The student's assessment and understanding of their performance is the key learning outcome.
- The Canal game variant is used to force the student to apply the knowledge learnt in a different scenario.
- Weekly seminars/clinics are run where students can access module staff for assistance
- Student feedback is collected as follows:
    - Automated in game feedback (triggered at tutor defined progress points).
    - Through student generated in-game messages to both game umpire (technical queries on the game itself such as UI problems and bugs) and to fictional head office (project/scenario related queries and reporting)
    - Standard university feedback mechanisms
    - Informal semi-structured interviews with students
    - Recording of student queries at weekly seminar/clinics
- Traditional teaching materials are provided to students but they are not forced to view them, though it is recorded when they do. These include sets of lecture notes, presentations, links to appropriate websites and references to key published work in the subject area.
- Assessment is based on a single piece of coursework (30%) and an examination (70%)
- Coursework is a report to the directors of the company that the student is employed by in the Muck game or Canal variant. The report focuses on a single run of the game, chosen by the student, and the student is tasked with the production of a suitable report that their managers would wish to see reviewing the project and providing lessons learnt for future projects.
- No guidance on report content, length and style is provided deliberately to test the students' ability to write concisely and clearly and to tailor their report to

their audience. This non-technical skill had been highlighted by employers as a skill that is often lacking in otherwise well educated and qualified graduate engineers.

- A set of potential examination questions given to students at start of module. Students are provided with all potential exam questions and told that four of these questions will be included on the exam paper, of which they are required to complete three questions.
- Each examination question requires the student to discuss and describe a key issue in the management of construction projects and expects them to make specific references to their experiences from playing the games in order to fully answer the question. The questions range from general issues in project management such as Micro. Vs. Macro management of projects to specific issues such as the use of variances alone to control a project. An example set of exam questions is provided with the module description form in appendix F.
- Students are monitored continuously and records kept of all their actions in the games through the MCG Umpire tool.
- The module has been in place at Nottingham since academic year 2005/2006 and is offered as an optional module for MEng (year 4 undergraduates) and MSc (postgraduate) students.

8.3 ACPM module operational details

In this section, the main elements of the ACPM module are detailed along with a description of key events and changes occurring during the operation of the teaching module. Feedback from students and from teaching staff is discussed and some examples are given of how this feedback was used to further develop and improve the teaching module.

An overview of module operation and results is followed by a breakdown by year from the module’s inception in the academic year 2005/2006.

8.3.1 ACPM Overview

Section 8.2 described the design of the ACPM module; the teaching and learning process, assessment methods, module requirements and student feedback mechanisms. In this section the practical implementation of key elements of the module are discussed in general terms

8.3.1.1 Introductory Lecture

The introductory lecture to the ACPM module has been presented in a traditional lecture format and is a two hour lecture session. The primary purpose of this lecture has been to ensure that students are fully aware of the requirements of the ACPM module and how it differs from a traditional lecture based teaching module. The ACPM module requires a great deal of self-directed learning from the students and it is made very clear to them in this introductory session what this means. The requirements and commitments of self-directed learning have been increasingly emphasised with each year of the module. This aims to ensure that students who are more predisposed and suited to a traditional tell-test approach to teaching are given pause to rethink their decision and can undertake the module with full knowledge of its requirements.

At the introductory lecture students are provided with the instructions for the Muck and Canal games (see appendix G), a module description and the set of potential examination questions for the module (example for academic year 2008/2009 given in appendix F). An overview of the two simulation games is presented and instructions for their operation are given, Module assessment requirements are detailed along with the learning process to be adopted throughout the module. The weekly clinic sessions are described and the teaching staff introduced to the students.

Once this has been carried out, students who are still interested in taking the module are asked to provide their student ID and username for the university computer network. This is required in order to provide them with access to the games on the university network and ensure that all the files required by them to run the games are in place in time for the first of the weekly clinic sessions. In return, the students are given User IDs for the Muck and Canal games. These consist of four letters followed by a single digit (1-4) for each of the four runs of the games for the student. Initially User IDs were not provided until the first weekly clinic session but this was changed in the second year of operation to enable the students to be able to use the simulation games as soon as possible. This is achieved by generating the game User IDs prior to the introductory lecture based on the potential applicants for the module (supplemented by an allowance for late applicants to the module and to allow for any technical problems).

8.3.1.2 Weekly clinics

The weekly clinic sessions represent the major source of teaching support in the module and have remained essentially fixed in their format and operation throughout the years of running the ACPM module. The clinics are carried out in university computer labs in two hour sessions. Students not on the ACPM module wishing to use the labs are disallowed or requested to use specific sections of the lab (depending on the ACPM class size) to ensure that teaching can be carried out without distraction.

Students are given no formal direction during the clinics. Relevant module or course announcements are made at the commencement of the clinic. Module issues highlighted or requiring clarification by the students during the clinic may also be raised and discussed with the entire class but otherwise students are left to direct their own learning. Between 3-4 members of teaching staff, including the author and PhD supervisor, roam the clinics responding to student queries and checking on student progress in an attempt to ascertain any obstacles to learning and give the students some direction where necessary.

There were some minor changes to the operation of weekly clinics throughout the years of the module's operation and a number of potential changes identified and proposed for future years of teaching. Specific details of these changes are given in the relevant following sections for each year of operation and future development plans for the ACPM module.

Teaching staff are careful to encourage the students to learn for themselves and direct their queries to the appropriate material rather than giving specific answers to questions (with some obvious exceptions for simple queries). Students are asked to clarify any query and are often able to solve the problem for themselves during this clarification phase. The involvement of their peers is both allowed and encouraged in the pursuit of answers to their queries to encourage discussion between the students regarding the issues covered in the Muck and Canal games.

Students are allowed to work alone or in groups during clinic sessions. Those working in groups often collaborate on a single run of one student or work competitively on their own run whilst discussing progress and strategies. It has been anecdotally noted that those students working in groups typically achieve better results in the module than those working alone. It is thought that the collaboration or competition combined with discussion between group members increases understanding and encourages reflection.

8.3.1.3 Monitoring and communication methods

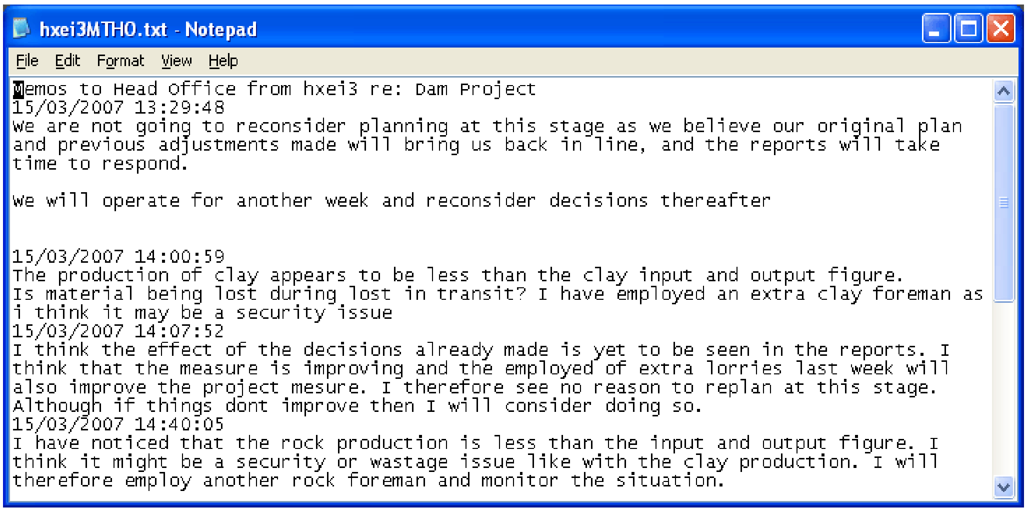
In addition to their use of the games at the weekly clinic sessions, students are able to play the games at any time during the module from a computer on the university computer network (which offers 24 hour access to students). In order to ensure that students are able to raise any significant learning issues or technical issues regarding the simulation games it is crucial that students can communicate effectively with teaching staff. Conversely, it is important for staff to be able to reply easily to the students and be able to message all students in-game with any important announcements or changes to the games or the simulated project data.

For example, in academic year 2007/2008 alterations to the fines imposed for health and safety infractions were increased on completion of the coursework phase of the project and this information was messaged to all students through the in-game messaging system and displayed on the main menu ticker control (Students were also emailed this information and informed verbally at the next weekly clinic session).

The in-game messaging system (see Figure 8.1 utilises a simple window allowing the student to type in their message and send it to either the Umpire (for technical and interface issues related to the games) or to Head Office (for queries related to the actual project itself). The in-game feedback questionnaire described in chapter 5 also utilises the messaging system. The students' responses to the feedback questionnaire are added to the memo to umpire file for each student. Examples of messages received from students during the operation of the course are shown in figures 8.2 to 8.4.

Figure 8.1: Screenshot showing an example message to Head Office in the Muck Game

In addition to the messaging system, student progress was monitored through the use of the MCG Umpire during the running of the ACPM module. As described in chapter 5, the umpire tool can be used to examine student progress and data to date. This was commonly utilised in responding to student queries. The umpire is able to view data that is not available through the Muck or Canal game interfaces and this proved useful in dealing with student queries and problems throughout the operation of the module. MCG Umpire is also used for regular monitoring of all students during the module's operation. It produces automated reporting on recent messages from and current progress on all registered players for the use by teaching staff.



hxei3MTHO.txt - Notepad

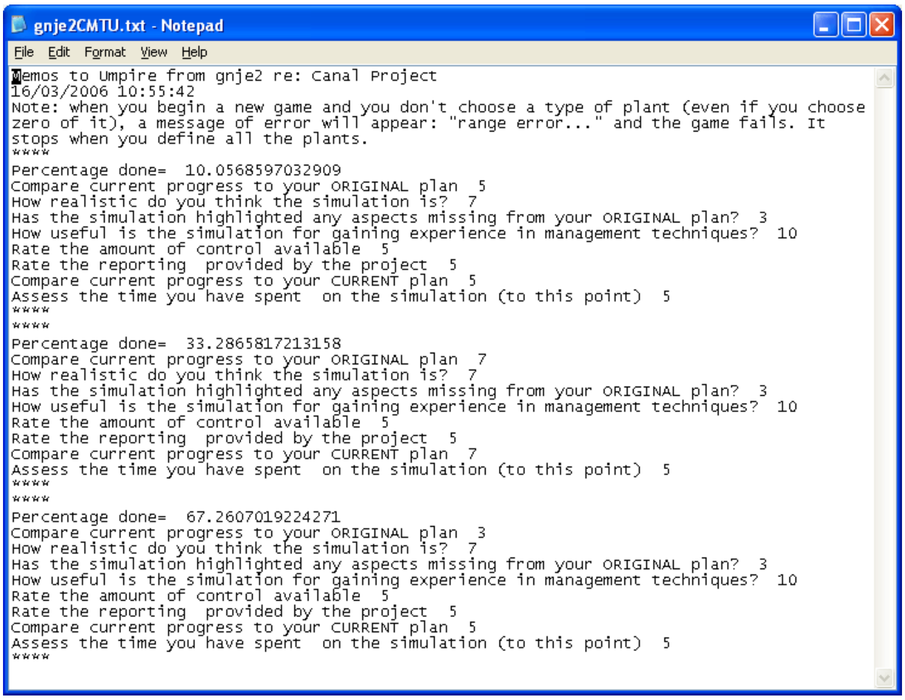
File Edit Format View Help

```
Memos to Head Office from hxei3 re: Dam Project
15/03/2007 13:29:48
We are not going to reconsider planning at this stage as we believe our original plan
and previous adjustments made will bring us back in line, and the reports will take
time to respond.

We will operate for another week and reconsider decisions thereafter


15/03/2007 14:00:59
The production of clay appears to be less than the clay input and output figure.
Is material being lost during lost in transit? I have employed an extra clay foreman as
i think it may be a security issue
15/03/2007 14:07:52
I think the effect of the decisions already made is yet to be seen in the reports. I
think that the measure is improving and the employed of extra lorries last week will
also improve the project mesure. I therefore see no reason to replan at this stage.
Although if things dont improve then I will consider doing so.
15/03/2007 14:40:05
I have noticed that the rock production is less than the input and output figure. I
think it might be a security or wastage issue like with the clay production. I will
therefore employ another rock foreman and monitor the situation.
```

Figure 8.2: Example message to head office received from user HXEI (3rd playthrough) in academic year 2006/2007

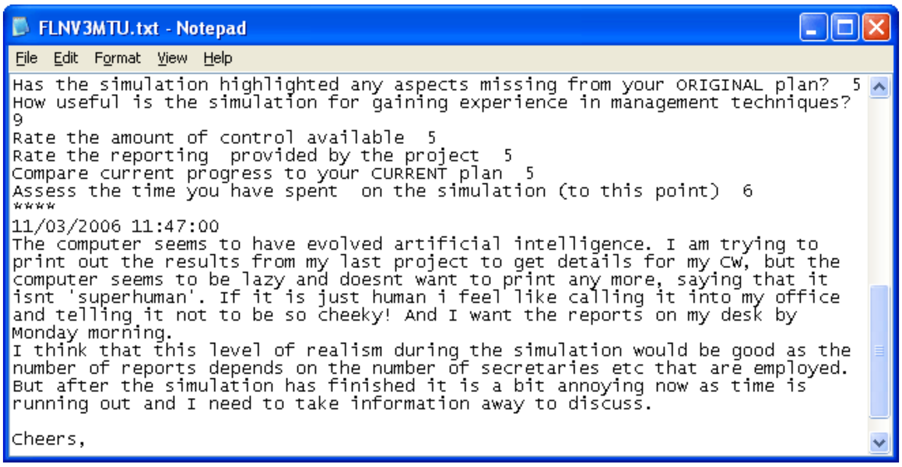


gnje2CMTU.txt - Notepad

File Edit Format View Help

```
Memos to Umpire from gnje2 re: Canal Project
16/03/2006 10:55:42
Note: when you begin a new game and you don't choose a type of plant (even if you choose
zero of it), a message of error will appear: "range error..." and the game fails. It
stops when you define all the plants.
****
Percentage done=  10.0568597032909
Compare current progress to your ORIGINAL plan  5
How realistic do you think the simulation is?  7
Has the simulation highlighted any aspects missing from your ORIGINAL plan?  3
How useful is the simulation for gaining experience in management techniques?  10
Rate the amount of control available  5
Rate the reporting  provided by the project  5
Compare current progress to your CURRENT plan  5
Assess the time you have spent  on the simulation (to this point)  5
****
****
Percentage done=  33.2865817213158
Compare current progress to your ORIGINAL plan  7
How realistic do you think the simulation is?  7
Has the simulation highlighted any aspects missing from your ORIGINAL plan?  3
How useful is the simulation for gaining experience in management techniques?  10
Rate the amount of control available  5
Rate the reporting  provided by the project  5
Compare current progress to your CURRENT plan  7
Assess the time you have spent  on the simulation (to this point)  5
****
****
Percentage done=  67.2607019224271
Compare current progress to your ORIGINAL plan  3
How realistic do you think the simulation is?  7
Has the simulation highlighted any aspects missing from your ORIGINAL plan?  3
How useful is the simulation for gaining experience in management techniques?  10
Rate the amount of control available  5
Rate the reporting  provided by the project  5
Compare current progress to your CURRENT plan  5
Assess the time you have spent  on the simulation (to this point)  5
****
```

Figure 8.3: Example message to umpire received from user GNJE (2nd playthrougth) in academic 2005/2006



FLNV3MTU.txt - Notepad

File Edit Format View Help

Has the simulation highlighted any aspects missing from your ORIGINAL plan? 5
How useful is the simulation for gaining experience in management techniques?
9
Rate the amount of control available 5
Rate the reporting provided by the project 5
Compare current progress to your CURRENT plan 5
Assess the time you have spent on the simulation (to this point) 6
****
11/03/2006 11:47:00
The computer seems to have evolved artificial intelligence. I am trying to
print out the results from my last project to get details for my CW, but the
computer seems to be lazy and doesnt want to print any more, saying that it
isnt 'superhuman'. If it is just human i feel like calling it into my office
and telling it not to be so cheeky! And I want the reports on my desk by
Monday morning.
I think that this level of realism during the simulation would be good as the
number of reports depends on the number of secretaries etc that are employed.
But after the simulation has finished it is a bit annoying now as time is
running out and I need to take information away to discuss.

Cheers,

Figure 8.4: An example of a rather confused message to the umpire received from student FLNV (3rd playthrough) from academic year 2005/2006

8.3.1.4 Gameplay and simulated project scenarios

As discussed in chapter 3, one of the critical issues in using simulations and games for teaching is in the design and definition of the simulated scenario to be used. Make the scenario too difficult and complex and it increases frustration leading to a loss of engagement. Too easy and it does not force the student to think about their actions and becomes boring. Gauging the level of difficulty and complexity appropriately for all students is not a trivial task.

Luckily for the development of the ACPM module, the Muck Game had been extensively used in teaching for many years and had been recently employed as described in chapter 7 (see sections 7.1 and 7.3). Feedback from this previous work was used to develop appropriate scenarios for the Muck and Canal Games for their use in the ACPM module.

A decision was taken to keep the parameters for the Muck Game essentially identical to those used in previous teaching at Nottingham University and Twente University (section 7.1). The climate data for the Perth area of Australia, used with the Muck Game at Curtin University (section 7.3), was chosen to be used with the Canal Game. It was felt that this would allow the students to experience the effect of a change in climate on managing this type of large earthmoving project. Tables 8.2 and 8.3 shows the rainfall data used for the Muck and Canal Games respectively.

MONTH	MEAN (mm)	ST. DEV. (mm)
January	142.75	32.00
February	107.95	25.65
March	78.23	24.89
April	76.45	19.56
May	75.69	11.94
June	72.90	7.87
July	89.15	7.62
August	108.2	14.22
September	118.11	29.72
October	146.81	37.59
November	145.8	38.35
December	127.25	28.96

Monthly rainfall.
(Average of last 50 years)

Table 8.2: Rainfall data for the West Yorkshire region of the UK used in the Muck Game

For the first two years of operation there were no changes made to the simulated project scenarios. The focus was instead on ensuring the successful operation of the module and that the two games were functioning appropriately. From the perspective of this research work it was also deemed to be essential that a large set of student data was collected using the same baseline simulation.

MONTH	MEAN (mm)	ST. DEV. (mm)
January	9.12	3.01
February	13.14	5.62
March	19.09	20.03
April	46.29	19.56
May	123.15	50.45
June	182.90	30.54
July	173.45	32.45
August	135.70	41.24
September	80.30	16.54
October	55.23	14.09
November	22.10	10.67
December	14.10	5.43

Monthly rainfall.
(Average of last 50 years)

Table 8.3: Rainfall data for the Perth area of Western Australia used in the Canal Game

After the second year of operation it was decided to change the settings of the simulated projects. These were made in order to examine the impact of changes in project difficulty and length to the learning process. This would also reduce the ability of students to simply copy the strategy of previous students on the module rather than truly engaging with the games and understanding the simulated projects.

After extensive testing it was discovered that the complexity of the simulations meant that even the most minor of alterations to the project start date or income could lead to major changes in the difficulty, length and strategic possibilities of the simulation. For example, the initial project settings for the Muck Game had a start date of 1st April and utilised the rainfall figures for West Yorkshire (Table 8.2). This meant that it was possible for a student to complete the project before the heavy rainfall season began in October. This was not possible with a start date of 1st June used with students in the 4th year of operation. This eliminated the possibility for avoiding operation during the winter and meant that students had to decide on a strategy for working through this wet period.

It was enlightening to identify the degree to which minor alterations to the simulation impacted on the learning experience for different students over the operation of the module. Some groups of students were clearly engaged by the additional challenge offered by increasing the difficulty whereas other groups became frustrated by their poor performance. Students also discovered strategies for managing the projects which had not been indentified during the extensive testing period.

8.3.1.5 Student Feedback

What did you like about this module?	How could this module be improved?
“Self-directed learning”	“Same structure of module for years 1-3 as well”
“It’s not a usual lecture”	“Provide a bit more information at the start on how the simulation works”
“The simulation gives a chance to see what trouble it is to manage a project”	“make dam project profitable”
“small numbers” “high lecturer/assistant to student ratio”	“make canal harder”
“like this approach, different to most other modules”	“coursework is hard when so little on what is actually wanted and lack of report writing is given”
“this is a much better way to learn construction management”	“feedback sessions with each student presenting a game every week would be good”
“great improvement for teaching this kind of work”	“game presentation and interface could be tidied up a bit”

Table 8.4: Feedback comments from students on APM teaching module (2007/2008)

Qualitative feedback from the students on the ACPM module has also been crucial to the ongoing development of the learning experience and helped to make appropriate changes to both the simulation games and the teaching module. Qualitative feedback is gathered through a variety of methods including in-game messaging, student queries in weekly module clinic sessions and through the formal end of module feedback forms completed for all modules at the university. Examples of comments taken from the student’s in-game feedback and module feedback forms are shown in table 8.4. Overall, positive comments were far more prevalent than negative ones and many of the answers relating to improving the project were constructive criticism, contradictory or were requests to increase the usage of this type of learning in the student's other modules.

Qualitative feedback has lead to many changes to the teaching method employed and the game itself. Some of the major changes discussed in this chapter were brought about due to student feedback such as the messaging system. Qualitative feedback from Curtin students (Scott et al, 2004) was useful in the development of the some aspects of the Applied Construction Management module. For example, comments from Curtin students expressing that they would like additional attempts at the game as some time is spent learning how to use the game was a factor in the decision to move to multiple runs in the ACPM module.

8.4 ACPM 2005-2006 Session (1st year of operation)

In the first year (05/06) of running the ACPM module, the students were found be suited to the self-direct style of learning and enthusiastic about the module in general. The students were quick to start playing with the games and the majority treated their first, and in some cases second, run as a tool for learning the game's operation and user interface. They did not treat these initial run(s) as a serious attempt at completing the projects successfully. There were however a few outliers who struggled with the nature of the teaching in the module.

The relatively low number of students on the module (16) was beneficial for ensuring that an appropriate level of teaching support was provided to the students. It also ensured that a number of logistical and technical issues in running the Muck and Canal games in this format could be resolved without impacting upon the student's ability to learn and the level of teaching support offered to them.

The Muck game was most played by the students which is not surprising for a number of reasons; it is the game first presented to the students in the initial lecture, the project length is shorter, the scale and linearity of the project make it appear more manageable but most importantly it was the only game available to play at the start of the teaching period. Once students had familiarised themselves with the Muck game most were reluctant to attempt the Canal game until they had achieved a satisfactory level of performance at the Muck game.

The Canal game was not available to the students at the first weekly clinics due to technical issues outside of the control of the teaching staff. It was made available at the second weekly clinic on the 16th February 2006 but only a small number of students tried to run the Canal game as most were already progressing with the Muck game at this point. Results from this year of operation are used to illustrate what can be learnt from analysing each year of operation in chapter 9 (section 9.4.1)

8.4.1 Formal recording of student queries

For this initial year of running the module it was decided to make records of all student queries during the weekly clinic sessions. This was intended to ensure that interactions between teaching staff and students were maintained for the purposes of this research and for further development of the teaching module. A simple form was developed for this purpose and these proved to be very useful when reviewing the teaching module after its completion. In conjunction with the institutional feedback forms and in-game feedback from students they provided useful information for alterations to the module, games and in particular the instructional material provided to the students at the start of the module.

8.5 ACPM 2006-2007 Session (2nd year of operation)

The second year of operating the ACPM module saw an increase in student numbers of over 400%. It is unknown as to a specific reason for huge increase but it is suspected to be due to a number of coincidental factors including good word of mouth regarding the module, the (false) impression that the provision of exam questions on starting the module meant that this module would be easier to complete with good marks and a genuine desire to try a different method of teaching.

8.5.1 Class size and logistical problems

The large class size was seen as being likely to prove problematic in a number of areas from the logistical issue of finding suitable computing facilities for the weekly clinic sessions to the practical issue of supporting such a large class of students without the benefit of additional staff resources. Unfortunately, institutional regulations meant it was not possible for the student numbers taking the module to be restricted in any way. Weekly clinic sessions had to be divided into two parallel sessions as it was not possible to accommodate all the students in a single computer room. Staff time had to be split across the two sessions. This inevitably reduced the contact time with the students substantially. In addition to logistical issues in running such a large class, there was also a much greater range of ability within the module this year. This combined with the larger class size lead to greater difficulties in running the module. There was a much higher proportion of students who seemed unsuited to this teaching method even accounting for the larger intake.

8.5.2 Student support issues and the MCG Umpire

During operation, a small number of students complained about the lack of fixed structure within the module. This was despite it being made very clear to them in the introductory lecture session that the module did not follow a traditional tell-test approach and that it required a large commitment of time and self motivation from the students. The issue was resolved by increasing the support available to those students seen to be struggling. This process was made much easier through the use of the MCG Umpire tool which fully proved its worth with such a large class of students. MCG Umpire's ability to monitor student performance enabled the teaching staff to monitor ongoing progress and be more proactive in supporting the students.

The MCG Umpire messaging system was also used more extensively in this year due to the increased number of students. It enabled students to contact the teaching staff with specific queries outside of the weekly clinic sessions. Student queries could then be quickly resolved by message or by arranging a meeting with the student (or group of students) at the next clinic session. An extreme example of a student who sent a large number of messages to the fictional head office is shown in table 8.5. The student chosen is also used in the analysis of individual student performance in chapter 10 and is referred to there and here as *student #7*.

Date	Day	Message
15/03/2007 13:29:48	11	We are not going to reconsider planning at this stage as we believe our original plan and previous adjustments made will bring us back in line, and the reports will take time to respond. We will operate for another week and reconsider decisions thereafter
15/03/2007 14:00:59	30	The production of clay appears to be less than the clay input and output figure. Is material being lost in transit? I have employed an extra clay foreman as I think it may be a security issue
15/03/2007 14:07:52	32	I think the effect of the decisions already made is yet to be seen in the reports. I think that the measure is improving and the employed of extra lorries last week will also improve the project measure. I therefore see no reason to replan at this stage. Although if things don't improve then I will consider doing so.
15/03/2007 14:40:05	50	I have noticed that the rock production is less than the input and output figure. I think it might be a security or wastage issue like with the clay production. I will therefore employ another rock foreman and monitor the situation.
15/03/2007 14:45:30	53	I will continue to the end of the week as planned and then make changes if necessary
15/03/2007 14:59:12	60	The project is on track duration wise and extra expenditure has had to be made for QSE reasons. The negative balance was planned for at this stage in the project.
15/03/2007 15:32:02	76	The financial state of the project is at risk due to the unforeseen break failure that took place that has caused the project to fail behind schedule. To get back on track extra plant has been required which has caused extra expense. I will continue up to the end of the week as I think things will improve.
15/03/2007 16:23:16	117	Maintenance issue has caused us to lose 2 days; I will continue with the present plan but will increase safety training and quality training by 50 respectively.
15/03/2007 16:31:05	121	Measure appears to be high but it will get better, the actual heights of clay and rock are in line with the plan and the expenditure should come down when plant starts to be laid off.

Table 8.5 : Memos to Head Office from hxei3 (Student #7) re: Dam Project

The run of the Muck game is the first game student #7 fully completed. Previous attempts incurred significant financial losses and showed poor performance to plan. In this attempt, the third, student #7 completed the dam construction within the deadlines and made a small profit.

Figure 8.5 and Figure 8.6 show additional data for student #7 created in the MCG Umpire tool. In Figure 8.5, the requirement and availability of a specific resource type (Lorries) is shown. Student refers to changes to lorry allocation in their message and these changes can be seen in the graph.

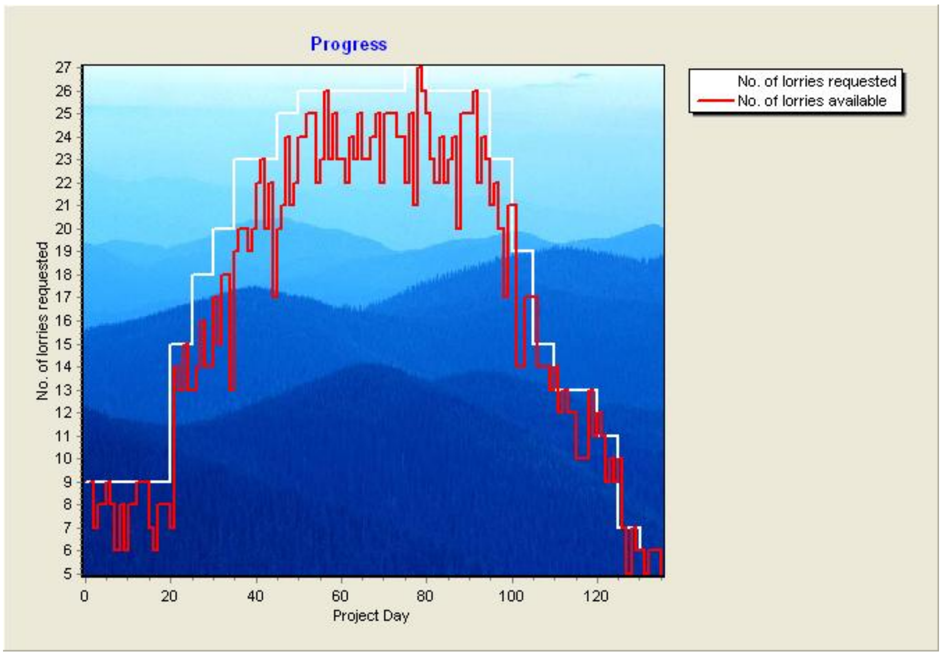


Figure 8.5 : Graph of lorry resource requested and available throughout project for student #7- User HXEI3 Muck game

Figure 8.6 shows the S*ummary Measure* for student #7 over the course of the simulation. The Summary Measure is described fully in chapter 9 (section 9.2) Essentially it is a composite measure assessing student performance to plan in terms of progression and finances where high values represent poor performance to plan and low values indicate that the project is running closely to the plan. Poor performance can be seen to occur between day 70 and 110 which can be related to the messages to head office sent on those days. It can be seen from the two example graphs provided how the teaching staff can generate graphs in response to the messages and assess the degree of support required by the student.

In this instance all the message to head office were sent within a three hour period so it would have been difficult for the teaching staff to respond quickly within such a short timeframe without the addition of significant levels of teaching staff employed to monitor student messages regularly. The messages were viewed on a daily basis and do provide an effective log of student reflection and learning.

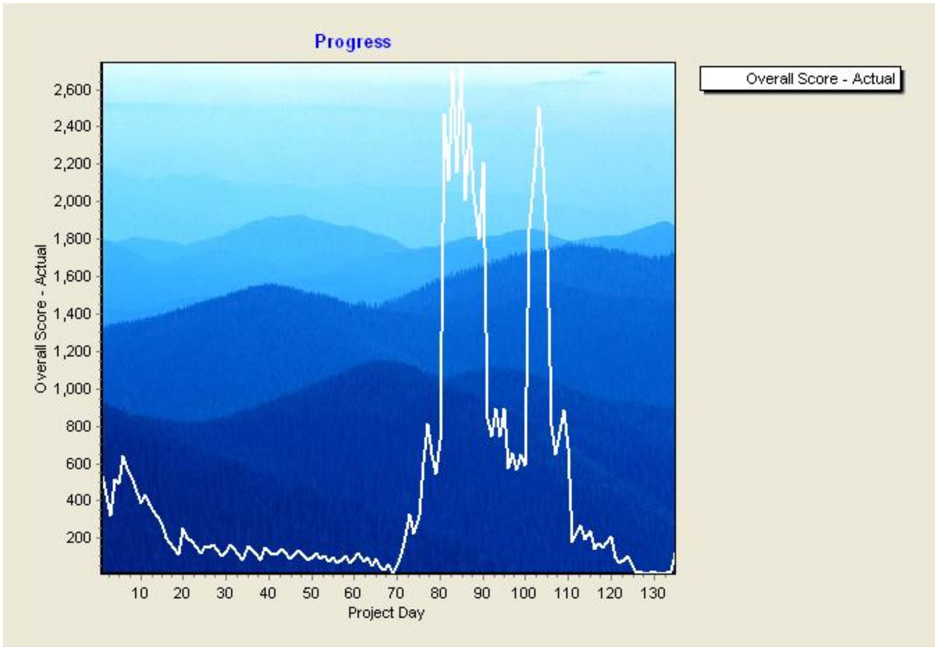


Figure 8.6 : Summary Measure for student #7 (user HXEI3) Muck Game

8.5.3 Modifications to the operation of the module

Additional functionality to add messages to specific students onto the *ticker tape* message box (see Figure 8.7) on the simulation games' main menu screen was implemented this year. This was useful in sending urgent messages to a specific student where concerns over their progress were flagged using the MCG Umpire. It also allowed the teaching staff to respond quickly to student queries. This functionality could also be used to message all students within the module to inform them of important module news such as changes to rooms for clinics.

Figure 8.7: Illustration of ticker message control on Canal Game main menu

In addition to any specific messages, the *ticker* control displays summary information on the current state of the project such as project date, progress, performance rating and cashflow.

8.6 ACPM 2007-2008 Session (3rd year of operation)

The third year's intake of students showed a marked tendency for greater planning and extensive reviewing of the project documentation. A large number of students requested additional runs for use in reviewing the exam questions. It was agreed to give each user four additional runs for both games. However, timetable constraints and the introduction of a more traditional programme of revision lectures this year meant that few of the students utilised the additional runs to any significant degree.

The number of students taking the module in this year was a more manageable class size of 23 students. This made it much easier to provide the students with the support they required and meant that the weekly clinic sessions could include all students. In light of feedback from the earlier years of running the module it was decided to run a series of revision classes or debriefing sessions in the period after the submission of the coursework element of the module. The data acquired and analysed for this year is discussed in chapters 9 and 10.

8.6.1 Student Interviews & Feedback

A number of informal, semi-structured interviews with individual students and groups of students were carried out. The interviews were aimed at going beyond the in-game feedback and formal module feedback forms used in previous years. The interviews enabled greater clarification and understanding of the student's responses to the games by establishing a dialogue with them. A basic set of questions was utilised but these were intended to provide starting points for the dialogue rather than to be strictly adhered to in the interviews. Notes taken from the interviews are shown in table 8.6.

The notes taken during this informal interviewing phase are included verbatim to ensure that nothing was lost in translation. The notes were not taken in front of the interviewees but were recorded immediately after the interview. This was done in order to avoid giving the students the impression that they were being formally interviewed and to assist in gaining the most truthful feedback possible given the fact that they were communicating with a member of the teaching staff.

Semi-Structured Interviews with students from year 3 of ACPM operation
UserName - HVZI 29/02/08 completed 3 Dam Starting Canal **MEng Student Type – Enthusiastic and self-motivated** *User thought the module was very different to everything else done as part of his course. Liked the approach and felt that initial lectures would not have added anything to the module.* *Found it difficult at first to get started with such little guidance but once a game was underway soon appreciated the choice for providing less guidance. He felt that the module was structured in the correct way for the material in hindsight but had found it tricky initially (mainly as it differed so greatly from other teaching)* *Thought that the game taught him a valuable set of skills that he would not have been able to learn in a tradition module. Student stated that he thought that this module would provide useful skills for his employment in the construction industry* *If lectures were to be employed he felt that they should be at the mid or end point of the module to act as a debriefing and reviewing session. Student has spent a study year in the USA and felt that the module was more similar to the teaching approach employed there.*
29/02/08 Interview with group of three students (MEng) ***Completed "some" runs of canal game – Student type – enthusiastic and committed*** *Have some frustrations with the games from a gameplay aspect, namely, they would like to be able to run for a set number of days without interruption unless a major event occurs. The loss of days due to incident is also frustrating.* *Don't see the lack of lecture based teaching as a problem though think there could be more assistance to initially get to grips with the games UI.* *They mentioned the possibility of having feedback sessions with each student presenting a run of the game so that they could get more of a feeling for what other classmates are doing/have done.* *They did feel that the module is very different to most of the other modules. They drew a comparison with the group design projects work undertaken in their third year. They thought it would be useful to introduce more of this style of teaching earlier in the course as it would benefit them more then. Discussed the potential for a simpler game (concrete floor slab construction)* *They found some of the randomness in the games (i.e. probability of event happening) frustrating but understand the need for it to be random Overall they felt that the module was a very useful learning experience (though with frustrations (mainly down to game design) at times) that was more closely related to industry than most of the teaching and learning they have encountered*
07/03/08 Interview with User DESC MEng – ideal student type? *Student enjoyed using the games greatly. Felt that this was a much better way to learn construction management type skills. Felt that the approach was probably not suitable in other modules within the course though.* *Found the Dam game (completed first) much harder than the canal game. Student liked the fact that once he started on the canal game it used the same UI and structure making it much easier to use first time. He enjoyed the challenge of improving with each run.* *Did not feel that different difficulty levels were needed but did think the canal game was too easy to make ridiculous sums of money*
*0**7/03/08 Interview with User JEJO – student type- analyser*** *Student completed canal game but not attempted muck game yet due to IS network drive mapping problem* *Student had extensively analysed the workings of the game and had a number of technical queries relating to its working, e.g. potential drop in lorry productivity over time as haul distance increased. Discussed these issues at some depth along with the development of the games over time. The student was very impressed with the games as a method of teaching construction management. Found it to be a much more effective tool for dissemination than a lecture based approach.* *Discussed a number of issues with presentation, UI and module design. Student appreciated reasons for choices though felt that the games could be tidied up from a UI perspective and would be highly marketable.* *Talked about differences between US and UK approach to teaching construction. US more practically based, UK more theoretical but this is partially due to his ability to specialise in construction in the US engineering degree. He felt that there was a lack of this type of teaching the USA. Student was effective at utilising the in-game communication options and looking beyond the stated figures for any discrepancies.*
07/03/08 Interview with EWLH3 (Muck) MEng Student – classic traditional student. *Student had some specific issues where he felt the information provided had been inadequate or incorrect. Explained the reasons for this. Student felt that this was a good way to teach con man but would have appreciated some additional lecture(s) initially to go through some of the material and game UI issues.* *This student was the only one so far to report the discrepancy in the muck game between overrun costs in handout (£50,000/week) to overrun cost in game (£50,000/day). However, he seemed very unsure about reporting it via the game.*
07/03/08 Interview with JWXT (Muck) – more traditional student? *Discussed the practicalities of planning and re-planning a project. Student found that it takes a number of runs to understand the extent of the interdependencies involved in the project.* *Discussed the realities of planning to make a loss for a construction project. Student seemed happier with the whole concept once explained in terms of build and operate contract structure where maintenance will recoup*

construction losses. *Asked student how he felt the game matched up against traditional lecture based teaching. He expressed that is was a great improvement for the teaching of this type of work.*
Other issues raised by students *Number of students reported initial difficulty switching from Dam to Canal due to the difference in scale and particularly with the removal of the hill at the start of the canal project.* *Once they reviewed the diagrams it was fine. Familiarity with the dam project meant that they were initially unable to register the vast increase in rock movements needed.*

Table 8.6 : Notes from semi-structured interviews with students

A number of students provided feedback at the end of the module that they would have found it useful to have a session early in the module where they presented their work to their peers and to the teaching staff. They were asked as to whether they thought this should be an assessed element of the module but unanimously agreed that it should be for formative purposes only. The teaching staff discussed this feedback and decided to include student presentations in the next year of the module to determine its utility.

8.6.2 Modifications to the module

This was the first year in which the students were able to play both the Muck and Canal games from the initial weekly clinic. Students were provided with usernames for the two games separately to ensure that around half the students were able to play the Canal Game before the Muck Game. It was hoped that this would lead to a larger set of students completing the Canal Game first so that the effect on performance of prior use of each game could be more thoroughly investigated.

Feedback from year 2 from some students indicated that they did not find the simulations challenging enough on repeated play. Analysis of monitoring data highlighted that it was possible for students to easily complete the Muck Game project prior to the onset of winter and that the Australian climate (with longer periods on dry weather) made it easier to complete the Canal project. It was decided to make some modifications to the simulation settings both to increase the challenge for the students and to examine the effects of the changes on their performance and learning from a research perspective.

8.6.2.1 Muck Game alterations and their effects on learning

Climate settings were changed to those for Perth (Western Australia) used for the Canal game in previous years. The project start date was changed to 01/02/2008 meaning that project started in late summer and that the students would be unable to complete the dam prior to the onset of heavy rain in Winter even if they worked at maximum productivity rates (this tactic had been commonly adopted by students in previous years to optimise performance). Experience using the game in previous years had identified a strategy of accepting safety problems as an inevitable cost of completion as the penalty was not a sufficient deterrent. Health and safety fines were doubled in this year to investigate the effect of student behaviour.

The changes to climate and start date had a significant impact on the difficulty of running the simulation with students struggling to complete the project within the temporal constraints and without making significant losses on their initial attempts. Some students complained about the increased difficulty but with support from teaching staff at clinic sessions most were able to complete the project (even if not able to produce a profit).

The viability of loss making projects and planning for this eventuality were discussed at length with students and it was felt that this gave them additional insight into the management and nature of large construction projects. It was discussed how construction and civil engineering contractors may take on a loss making project in order to secure further more profitable work with the client. Some students took this on board and treated the Muck and Canal games as a series of related projects where the profit made on the Canal game could be used to mitigate any losses made on constructing the dam in the Muck game.

It is not clear that the changes to safety fines made a significant impact on student behaviour though a number of students were found to pay greater attention to, and increase their spending on, health and safety issues. Quantitative measures of the effects of the changes to the game in this year are described in chapter 9.

8.6.2.2 Canal Game alterations and their effects on learning

The Canal game was changed to use the West Yorkshire, UK climate figures used with the Muck game in previous years. The Canal game had never been used with climate figures other than those for Perth in Western Australia unlike the Muck game which had been run with both sets of climate data. Since it was not fully known how the students would be able to manage the canal project under these settings it was decided to select a project start date that would allow the students a significant duration before the onset of wet weather. .The start date was therefore set to 01/04/08 meaning that students would have 6 months of good weather to make good progress on the project.

The duration of the Canal game project is longer than the Muck game. Completed projects average duration is 82 weeks (410 days) and the minimum is 47 weeks. This means that the player is less able to compress the project to avoid any periods of bad weather since it generally takes over a year (of simulated time) to complete. This should mean that changes to the climate conditions should have less effect on players of the Canal game except where there is interaction between poor weather conditions and initial stage of the project where the amount of rock to be excavated is much higher than average.

The effect of these changes seems to have been to increase the use of the Canal game as this year shows the highest relative use of the game. The profitability of completed Canal games is also increased over previous years. This is probably due to the fact that the most difficult stage of the project can be completed under ideal weather conditions.

Some students reported reduced interest in the Canal game once they had completed it once as they did not find it challenging enough. However, other students enjoyed the Canal game over the Muck game as they found the difficulty of the Muck game to be frustrating and instead enjoyed attempting to maximise their profit and minimise project duration in the Canal game. It seems evident that the differences in game difficulty between the games suit different groups of students; increasing engagement with one group whilst reducing engagement with the other group.

8.6.3 Introduction of debriefing / revision sessions

In light of feedback from the previous year in regard to the difficulty encountered by some students in directing their own learning it was decided to introduce revision classes after the completion of the coursework element of the module.

The classes were led by teaching staff but attempted to involve the students in a discussion forum rather than a traditional lecture based format. The sessions acted to debrief the students' findings from playing the games and provide insight into how these relate to the examination questions provided to the students. Each examination question was reviewed and discussed with particular attention paid to how the examples from the two simulation games might be relevant in answering the questions.

Feedback from students indicated that these sessions were found to be both useful and thought to increase their learning of the subject. However, since the total amount of student contact time remained the same as in previous years, the introduction of the revision sessions reduced the time spent running the simulation games. No significant use of the games occurred once the sessions began (except for a small minority of students and then mainly to access assistance materials).

8.7 ACPM 2008-2009 Session (4^{th} year of operation)

Academic year 2008/2009 is the last year for which data was collected as part of this research programme. Twenty three students undertook the module in this year and a number of modifications to the module content and the two games were made in light of feedback from the previous years of operation, the ongoing series of changes planned as part of this research programme, through feedback from presenting the work at international conferences and from meeting and discussions with colleagues and collaborators.

8.7.1 Technical Issues

A significant issue in operating the module in 2008/2009 was technical problems in running the two games over the university network. The first two clinic sessions were completed without the students being able to run the games successfully. Since the games had been run for the previous three years in the same manner with only minor problems relating to their operation this was an unwelcome and surprising development. The modifications to both games described in their respective sections below were not deemed to be a possible cause of the problem.

The problems appeared to be network related and were manifested by both games freezing during play. The root cause of this network problem was not fully discovered though its prevalence seemed to be related to the number of concurrent users of the games. The problem was eventually resolved but the students had lost a significant amount of available time to play the games. However, an unintended outcome of the IT problems in this year was the increased time for planning and reviewing the simulated project scenario by the students. This was evident in the increased pace of progress once students were able to run the games successfully and can be seen in the data on each game discussed in chapters 9 and 10.

This issue is worthy of note in this thesis as it highlights a significant constraint on the use of computer based simulation games for the purposes of teaching. The fact that it occurred after three years of successful operation of the games over a computer network demonstrates that even the most well tested and used simulation is prone to IT problems that can be outside the control of the teaching staff. When teaching is predicated by the use of network based computer applications then it is essential that effective collaboration between teaching staff and technical support is in place. It was only this close collaboration in this instance that prevented an IT problem becoming a significant teaching and learning problem.

8.7.2 Modifications to simulation settings and effects on teaching

Results from the analysis of student data in the previous year had identified that the addition of monitoring data on student planning throughout the simulation (rather than just recording the student's current plan as was done previously) could be useful for the research. Changes to the games and umpire were carried out to achieve this and data collected is illustrated and discussed in chapter 10.

Changes were made to the settings of the simulations in a similar way to those done in year 3. Climate conditions were reverted to their initial conditions with the Muck Game being run in West Yorkshire and the Canal Game run in Perth, Australia. In light of the findings on the large effect of changes to project start dates, it was decided to change this again for this year.

The start date for the Muck Game was changed to 01/06/09 meaning that the students would have an even shorter period of good weather at the start of the project. It was thought that this would make it more difficult for the students to complete the project successfully in their initial attempts and this proved to be the case for the majority of the students. Once initial difficulties were overcome and the workings of the game and interface were clear to the students, many of the students found that they enjoyed the challenge of completing the project with a profit which was not an easy achievement (only 13% of completed runs and 6 of the 23 students of the game made a profit).

The start date for the Canal Game was set to 01/04/09 which meant that the project was starting at the beginning of the wettest period of the year to see how this would affect the student's planning and project management. The low number of attempts at the Canal game in this year made it difficult to draw any conclusions on the effects of the changes to the settings. However, some students again reported that the Canal game was not challenging enough and the performance of students at the Canal game was very high. This could be due to the fact that all students completed the Muck game first and the increased difficulty of the Muck game made the Canal game seem a trivial task in comparison.

The other modification to the project settings was a small change to the points of progress at which the in-game feedback forms were activated. In previous years the feedback was triggered at 10%, 33% and 67% project progress but in this year it was changed to 10%, 47% and 88%. This was done to investigate if there was any effect on feedback from making the trigger points later in the project. However, it was not possible to confirm any significant effect from a single year's worth of results.

8.7.3 Additions to student data monitoring

Analysis of data from the previous year had identified that full details of all student plans should be added to the monitoring data collected by the MCG Umpire. This was done and the data collected was used for analysing student planning and is described in chapter 10 (section 10.2.4). This addition enabled examination of all student plans created during the simulations rather than just the original and most recent plan, which was the case before the modification.

8.7.4 Introduction of Group Presentations

As stated in section 8.6.1, it was decided to introduce presentations by the students in this year. As an initial trial of the utility of presentations within the teaching module it was decided to make the presentations a formative assessment exercise rather than an audited assessment. There would be no graded assessment of the presentations by teaching staff or students. The purpose of the presentations was to help the students gain feedback on their performance at the simulation game from the teaching staff and their peer group. It would also help students develop their presentation and communication skills.

For this initial trial of employing presentations it was decided to make the presentations an optional rather than a mandatory element of the module. It was also decided to allow, and encourage, the students to present their work in groups. This was done both for practical and educational reasons. Practically, it was not possible for each student to present their work individually within the constraints of the module timetable. Educationally, experience from previous years of running the module had shown that students working in groups seemed to perform better and learn more than those who worked alone. By encouraging students to present their work as part of a group, it was thought that this would increase group based working throughout the remainder of the module.

Four groups opted to present their work in one of the weekly clinic sessions. Feedback from the students was very positive for the exercise and it was also evident that the presentation of work aided many of the students in completing the Muck game successfully. Performance from the game was seen to significantly improve in result of the presentation session. It is thought that this was due to the fact that the presentations fostered some competition to match or improve on the performance of others. During the presentations, three of the groups stated that they thought it not possible to produce a profit on the Muck game. The final group presented their work and demonstrated that it was possible to make the project profitable. By the following week’s clinic session a number of students had completed profitable Muck game simulations.

8.7.5 Progression to a focus group based revision exercise

The introduction of revision classes in year 2 (section 8.6.3) was seen as a useful exercise but it was felt by the teaching staff that it could be improved by making the sessions more participatory and moving away from a lecture based format. It was determined from research, experience and discussion of similar work by others that a focus group format would be the best option for the revision classes,

This would require greater participation by the students and would be useful experience to those embarking on a career in the construction/engineering industry as the format chosen is now commonly used in industrial workshops.

A range of potential topics for the focus groups were outlined and debated for the exercises. Due to timetabling constraints (there were only two sessions available for revision once coursework was completed) it was decided to choose only two topics for discussion *Planning* and *Control*. Three group leaders were selected by the teaching staff and groups were formed around the leaders prior to the sessions.

At each session groups were tasked with the discussion of the specific topic in relation to the simulation games, actual construction projects and the examination questions. They were required to generate a set of key points and findings and then present these to the entire class. Teaching staff were available at the sessions to assist if needed but acted principally as interested observers. They provided input to the discussions only to help if the discussions became deadlocked.

Feedback to the sessions was positive where elicited though some students were not entirely comfortable with this style of learning initially. By the end of the two classes most students had accepted the approach and were involved in the discussions. It was felt that the approach was more successful than the revision classes used in the previous year as it required greater student input and the group presentations enabled all students to gain differing perspectives on the topics, learning outcomes and exam questions.

8.8 Reflections on the design and operation of the Applied Construction Project Management module

The ACPM module described in this chapter represents the major experimental work carried out as part of this research. In this chapter the module itself was described in terms of its aims, learning outcomes and key features. Details and modifications made during the initial four years of running the module were provided.

The ACPM module differs from most existing work in this area as its uses simulation games as the principal source of learning for an entire teaching module. It employs self-directed and blended learning methods by design (and institutional constraints) Students are offered a very different learning experience to others encountered during their course and the module is an option to all Masters level students. Self motivation and the ability to apply engineering judgment are essential to success in the module.

Assessment uses a traditional approach through coursework and examination, though untraditionally, the potential set of examination questions is available to the students from the commencement of the module. Performance at the simulation games is not part of the graded assessment for the module by design.

Outside of an initial introductory lecture to present the simulation games student contact is provided through weekly clinic sessions where teaching staff assist students in running the games.

Issues and findings from each year of operation highlighted a number of educational, practical, logistical and technical issues in this type of learning such as the high staff/student ratio needed and the impact of IT availability issues where it is essential for learning to occur.

A range of modifications were made during the operation of the module such as the introduction of additional in-game support and communication tools, changes to the simulation settings and difficulty and the introduction of other teaching methods including focus group exercises and group presentations.

Feedback from students was very positive in general and will be further explored with qualitative and quantitative data in the following chapters (chapters 9 and 10).

9. ACPM – Detailed data analysis and statistical findings

This chapter describes the quantitative data collected from the Applied Construction Project Management (ACPM) module in its first four years of operation. Analysis of all students and student groupings relevant to the research aims and objectives (section 1.2) are the focus of this chapter. A set of key variables are described and used to evaluate the data collected throughout the operation of the ACPM module. Methodology used to collect and analyse the data is detailed with specific discussion of errors found, their mitigation and the normalisation of data with this part of study.

9.1 Introduction

Statistical information and trends drawn from the student monitoring data is described and inferences are drawn relevant to the research questions and aims posed in Chapter One. In addition, audited assessment data for students is compared with the monitoring data collected during gameplay to examine and identify any correlation between game performance and results from the examination and coursework elements of the module.

Results and statistical analysis of the full set of data from the ACPM module is provided and described in sections 9.4 onwards with the initial focus on the entire set of data collected during the four years of operating the module covered in this research work. Data is then reviewed for each year ACPM module, ensuring that differences in the simulation settings between years are discounted. Final analysis of the data according to run iteration is then given to examine the effects of repeated play on performance and potential relationships to student learning. This relationship between learning and performance will then be further examined in relation to the performance of individual student's case studies in chapter 10.

9.2 Key Variables

The MCG Umpire generates a large monitoring dataset for each run of the Muck and Canal games. The data collected by the Umpire was expanded during the operation of the ACPM module. This was needed to: (1) reflect changes to the games themselves between the years of running the module and (2) to add content to the dataset in light of the results of analysing each year's monitoring data.

Examples of the data collected by the MCG Umpire are shown in appendices M and N. The full set of raw data collected during the operation of the ACPM module is provided in the e-appendices relating to this thesis. Much of the data collected is intended and most suited to analysis at the individual student level. For example, the resource levels throughout a project. However, other elements are suitable for analysis as a grouping of data, such as total spend or total time spent.

A set of key variables relevant for analysis for the full set of student data or for specific groupings was determined during the initial phase of analysis at the end of year one of operating the module (academic year 2005/2006). The set of variables remained largely constant throughout the operation of the module though there were some additions in light of early analysis. The full set of variables chosen for analysing groups of monitoring data are shown in table 9.1.

It should be noted that there is a large set of variables tracked that are not included in the set of variables. There was a range of reasons for the exclusion of variables, the three primary reasons for exclusion are:

1. The inclusion of a variable did not provide any additional information useful for high level analysis. For example, the breakdown of expenditure for rock and clay was not needed for high level analysis, the total expenditure was sufficient.
2. The variable was of relevance only when tracked throughout the project and not as a single figure or total for the whole project. In this instance, the number of a resource available or requested is not useful in the form of a single figure for the whole project.
3. The variable was outside the influence of the player. A good example of this would be the rainfall data. The rainfall varies according to the mean and standard deviations entered in the simulation and cannot be affected by the player. There would be little benefit in measuring the rainfall data for all students for comparison purposes[1].

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[1]There may however, be some use in looking at the rainfall data when comparing a set of simulations that were carried out under different climate settings.

variable	Description
UserName	The username for the Muck or Canal game which acts as a unique identifier for each user. Technically, this is not a variable but simply a property of each run but it is a required element of the variable data for identification purposes.
Run	The iteration of the game being played by the user. Typically, each user will use their runs in numerical order. ABCD1-4 but at times they will use them in a random sequence. This property is important in order to assess the degree of improvement shown by a student during iterations of playing the games.
Start	The date and time at which the user first logged into the game. This is another property rather than a variable but is needed to determine the specific *run* of the game.
Finish	The date and time when the user last logged out of the game. It is important to note that this is not the same as the date and time at which the user completed the simulation. This is another property rather than a variable in itself but can be a useful indicator when combined with *Start* and *Time.*
Time	The time in minutes spent logged into the game by the user. An important measure useful in determining the difficulty the user experienced in playing the game. It is however, prone to anomalous values where the user remains logged into the simulation whilst performing other tasks.
Days	The simulated project duration for the user measured in working days. This can be used to assess a user's rate of progress or to measure the rate of spend incurred. It is also an important measure in itself for comparing completed simulations.
Rock	The height of rock that the user has placed (for the Muck Game) or the length of rock excavated (for the Canal Game)
Clay	The height of clay that the user has placed (for the Muck Game) or the length of clay excavated (for the Canal Game)
%Done	A calculated value representing the project completion in percentage form. Derived from the Rock and Clay progress compared to the required height or length of Rock and Clay. The extent of completion by each user is an essential variable to enable the comparison of completed and uncompleted runs. It Is also a good indicator of student performance or engagement with the simulation games.
PlanSpend	Represents the planned expenditure to date for the simulation. A useful indicator of how well the user has planned the project financially.
ActSpend	The total money spent on the project to date. One of the most critical indicators of game performance since it is directly related to a student's ability to manage and control the simulated project. The value of this variable is determined by a player's management decisions. Improvement in performance at completing the simulation is likely to involve a reduction in actual spend over repeated runs.
Income	Money earned in playing the game to date. Since overall income is fixed it is not as useful an indicator as the planned and actual spend but is useful in comparing to those (and other) indicators.
NumPlans	The number of plans that the user made during the simulation. As stated in chapter 5, the Muck and Canal Game allow the user to make a maximum of 10 plans. The number of plans generated provides a good indication of the difficulty the user had in playing the simulation. It would be expected to see a user reduce the number of plans required to complete the simulation as their knowledge and experience of the game increases in repeated runs.
DailySpend	This indicator is a calculated value created by dividing the *ActualSpend* by *Days*. Useful in comparing runs for a user or a range of users. Can indicate a strategy for early project completion or a project where spending is out of control.
DailyProg	An indicator calculated by dividing the *%Done* by *Days* to show the rate of project progress for a user.
EndMeasure	The current *Summary Measure* value a run of the Muck or Canal Game. *Summary Measure* is a value used in the two games to give the user an idea of their current overall performance. It is a non-dimensional floating point value that is an aggregate of a number of measures (both financial and progress based). It is related to how closely actual performance matches planned performance for the simulation. A low value represents good performance to plan and a high value represents divergence from planned performance. Re-planning can be used to reduce the summary measure as it is measured against the current plan.
MaxMeasure	This the maximum value of *Summary Measure* throughout a run of the simulation. It represents the greatest divergence from planned performance during gameplay and is a good measure of a user's performance during a run.
RTypChange	The number times the user changed the type of resource during the simulation. Changing the type of resource repeatedly is an expensive and 'desperate' control measure. Therefore a high value for this indicator is likely to indicate the user having difficulty in playing the simulation game.

CGChange RGChange	These two values represent the number of times that a user altered the haul road gradients for the clay and rock haul roads respectively. As with the *ResourceTypeChange* variable, a high value for this is likely to indicate user difficulty, lack of understanding or a project out of control. In conjunction with the other variables mentioned it should help to confirm overall performance for a run of the simulation game.

Table 9.1: Key Performance Indicators and their descriptions

9.3 Data collection and analysis method

The MCG Umpire software was the generator of the data from playing the Muck and Canal games as described in chapter 5.3. Key variables were extracted from the umpire record files for all users from the four years of operation of the ACPM module. These were then collated and analysed to produce overall statistics and identify groups and individuals for further analysis. The detailed analysis of example individuals, including typical, extreme and anomalous, is discussed in the following chapter

In addition to the data on game variables, other information relevant to the aims of the research programme was collected such as examination and coursework results from the ACPM module. All student data is kept strictly anonymous throughout this thesis. Students are only referred to through an ID number or by their Muck or Canal Game usernames.

Student data was collected following the method outlined above on an annual basis at the end of each academic year. The sets of annual data collected will be described in this form in the section 9.4.

9.3.1 Errors and Corrections

Inevitably in any large data collection exercise errors in the recording and calculating of data do occur. All reasonable measures were taken to limit and correct for this in this research work and it is thought that data presented in this chapter is as accurate as is possible. Since the MCG Umpire was designed and developed as part of this research programme, results from analysis of each year of operation led to modifications and extensions to the umpire monitoring data and the quality of the data produced increased during each year of operation.

Specific errors in recording monitoring data from the ACPM module will now be discussed along with the measures taken to correct them if possible, eliminate their reoccurrence and to reduce their effect through other means where possible. Typical errors and mitigation measures taken related to them will now be described.

9.3.1.1 Monitoring data corruption

Student monitoring data is held on a central file server and network access is required to write the data, if the network becomes unavailable during the write process then incorrect or incomplete data may be written to the file. This can also occur if the games themselves (running from a separate file server) become unavailable or terminate unexpectedly during the logging of monitoring data then this could also occur.

9.3.1.2 Temporal errors

When recording temporal information to the monitoring data, errors occurred when a player was logged during a change of date. This caused the calculation of time played to record negative values. This was discovered in analysing data from year two of operation. It was easily fixed and errors were corrected as the start and end times and dates for each activity are logged. These were used to correct the *Time* value. It was caused by legacy code in the Muck Game (which was copied into the Canal Game) which used a simplified method for calculating time passed based only on the time of day rather than the date and time. It had not been spotted prior to this since prior use of the games had been classroom based and therefore not tested during a change of date.

9.3.1.3 Numerical overflows

In designing the format of the monitoring data files, assumptions were made as to the maximum values possible. Though these were designed based on maximum values seen in previous use of the games (plus a significant margin to allow for variation), it was found to be insufficient in some instances. This was identified and corrected during the analysis of year one's dataset. However, other instances of this problem did occur during the ongoing operation of the module. All were identified and corrected relatively easily but demonstrated that it is more difficult to define the range of variability in student performance when using the games in an unsupervised and self-directed learning style.

9.3.1.4 Umpire data omissions

No matter how much planning has gone into determining a set of variables to be monitored in an experiment, it is always likely that some omissions will be identified when reviewing the results. In a complex simulation such as the Muck and Canal Games, this is almost inevitable. Some omissions were due to weaknesses in the original planning but the majority were identified as useful additions to the analysis that could not have been easily foreseen. Dataset size and content was increased incrementally during the operation of the ACPM module. An example of this would be the addition of haul road condition variables to the monitoring dataset after the first year of operation.

9.3.1.5 Data resetting issue

It was discovered during analysis of monitoring data that on rare occasions progress at the game seemed to be reset during operation. This was initially thought to be due to an error in the games of some kind but further investigation revealed that this was not the case. Data was being reset due to students deleting the game data files that are held in their personal space on the university computer network. It is assumed that this was done because they were unhappy with their performance and wished to start again. This was despite the fact that they had been informed that they could request additional runs if they encountered difficulties in completing those initially provided. In total, this behaviour was exhibited by three students throughout the four years of running the module.

It is hypothesised that perhaps the players wished to remove the evidence of their poor performance. If this was indeed the case then it was a wasted endeavour since the monitoring dataset maintained the record of their previous attempts. This is of additional interest in terms of the research aims of this work as it demonstrates a type of behaviour that would have not been identified without the use MCG Umpire to track and monitor student performance.

9.3.1.6 Summary and reflections on the extent of errors in the study

As a final point, it should be emphasised that the errors and corrections highlighted in this section do not represent a significant issue and only affected a small proportion of the data collected (<5%). None of the errors noted here impacted the ability of the students to use the games, though network problems leading to data corruption in the monitoring data could also corrupt the game data files. This occurred on a few occasions and was corrected by using network backup files or by deleting and starting again where student progress was limited.

It is important though to highlight data quality, as it raises some important issues in the automated tracking and monitoring of students in an e-learning exercise. Also, data quality issues were responsible for identifying some interesting aspects of student behaviour and gameplay strategies that are further discussed in Chapter 10.

9.3.2 Data Normalisation

When examining the results of any scientific experiment it is common practice to normalise the data gathered in order to remove outliers and anomalous results that would distort the results of the analysis. When dealing with data that represents conscious human behaviour rather than physical measurements it is important to be very circumspect when normalising such data. Care must be taken in order not to exclude data that appears to be an outlier but in fact represents an alternate strategy for running the simulation.

A simple example of this would student data where the time spent on running the simulation is significantly higher (factor of 10) than for other comparable simulation runs. It is tempting to exclude this data as it significantly skews the average time spent playing the games but it is likely to represent a student who would simply remain logged in to the simulation for long periods of time whilst performing other tasks, reviewing the assistance materials or discussing the simulation with their peer group.

There are however examples where student monitoring data may be excluded from the analysis for the purposes of normalisation. The most obvious example of this would be data where the student spent some time logged into the game but did not advance the simulation at all during the entire run. This data is of interest in terms of looking at student behaviour but its presence in the analysed dataset would have significant effect on the statistical measures obtained. It is of course quite possible that this behaviour may represent a student who had encountered significant difficulty in progressing the simulation and if so it should not be excluded as it is a valid set of data. The best solution in this instance was to analyse the data both including and excluding runs with no simulated progress since both measures are of potential interest. This also enables analysis of the extent to which such anomalous data affects statistical averages and other measures derived.

In order to ensure that a true comparison of matching data can be achieved it was also considered as to whether only completed simulations should be analysed. This would have excluded a large degree of important data and biased the results towards those runs undertaken midway through the module since initial runs commonly terminate before completion due to difficulties encountered and later runs are often not completed due to the students running out of time. Conversely, it would have ensured greater comparability between data records and excluded a large percentage of the outliers in the overall dataset. It was decided to analyse the data for completed runs separately but in addition to analysing the full dataset. This provided the benefits of both approaches without the loss of potentially important results. In some instances the completed and uncompleted runs have been separated, analysed and the findings compared intentionally.

In the instance of the three students who replayed the Muck Game a number of times for some runs (see 9.3.1.5). A decision was taken to take their initial attempt at completing the simulation as the one to be included in the set of monitoring data to be analysed for that run. In one instance however, the initial run was terminated without any significant progress (<5% completed) and it was noted that the student reported problems in running the simulation at this point. Their second attempt was therefore included in the analysed data discussed in this chapter.

9.4 Game statistics by academic year

Table 9.2 provides statistics for the ACPM module broken down by year. The data shown in the table is a combination of data on simulation game performance and data from the teaching module. In examining the data shown in the table, it must be remembered that the settings of the simulated games was changed in years 3 and 4 and it is not therefore not possible to make a direct comparison of project duration. However, the fact that the statistics shown in table 9.2 include incomplete attempts at the simulation games means that the overall averages can be compared. From the data shown in table 9.2, the following can be ascertained:

1. Completion rates for Muck and Canal were broadly similar in years 2 and 3
2. Muck completion rates were significantly higher than Canal in years 1 and 4
3. The Muck Game is played more than the Canal Game in all years but this is especially true for years 1 and 4. Combined with the previous point this highlights the low use of the Canal Game in these years.
4. The results of assessment for all four years are of are broadly similar in terms of averages and standard deviations
5. Only one student failed the module during operation. Shown as the minimum mark for year 2 (17%). This student was not able to take the examination as he left the course due to personal issues. Their performance up to their departure was good and is shown by the 17/30 score for their coursework.
6. Coursework results are slightly higher than examination results on average
7. It is not possible to identify a statistically significant change in time spent on the games in subsequent runs from the data shown in table 9.2. Detailed analysis and removal of outlier data will be needed to examine this further.

Statistic	Year 1 05/06	Year 2 06/07	Year 3 07/08	Year 4 08/09
Number of students	16	66	23	23
Muck Games completed	41	115	36	52
Muck Games played	64	208	64	77
Completion %	64.1%	55.3%	56.3%	67.5%
Canal Games completed	8	67	36	11
Canal Games played	18	132	48	36
Completion %	44.4%	50.8%	75%	30.6%
Total games completed	49	182	72	63
Total games played	82	340	112	113
Total Completion %	59.8%	53.5%	64.3%	55.8%
Coursework (%)				
Minimum	60	53	47.1	55
Maximum	85	90	80	80
Mean	68.7	65.2	66.8	66.3
Standard Deviation	6.2	8.8	5.8	6.0
Exam Mark (%)				
Minimum	48.6	0	55	47.2
Maximum	78.6	79	83	75
Mean	65.4	61.2	66.9	61.8
Standard Deviation	7.9	7.4	6.4	5.5
Total mark (%)				
Minimum	52	17	49.5	51.5
Maximum	77	78	78.2	75
Mean	66.7	62.6	66.8	64.4
Standard Deviation	7.5	8.6	6.7	6.3
Mean time spent – Muck	**331.46**	**337.73**	**212.10**	**245.05**
Dam Game #1 (minutes)	379.04	370.83	268.80	312.89
Dam Game #2 (minutes)	328.96	318.80	206.45	265.94
Dam Game #3 (minutes)	309.92	400.70	247.51	189.63
Dam Game #4 (minutes)	297.93	189.79	137.81	156.01
Dam Game #5 (minutes)	N/A	971.33	108.36	N/A
Dam Game #6 (minutes)	N/A	N/A	100.58	N/A
Dam Game #7 (minutes)	N/A	N/A	22.17	N/A
Mean time spent – Canal	**184.09**	**250.53**	**300.46**	**172.43**
Canal Game #1 (minutes)	200.25	248.98	346.71	207.11
Canal Game #2 (minutes)	123.82	225.28	246.21	220.75
Canal Game #3 (minutes)	138.78	298.52	308.88	47.38
Canal Game #4 (minutes)	N/A	275.51	336.43	0.74
Canal Game #5 (minutes)	N/A	153.37	15.67	???
Mean project length - Muck	**140.86**	**137.93**	**164.50**	**157.08**
Dam Game #1 (days)	138.28	148.18	186.50	184.74
Dam Game #2 (days)	160.59	142.89	184.07	175.14
Dam Game #3 (days)	142.38	141.71	170.00	135.64
Dam Game #4 (days)	118.50	95.14	143.20	103.18
Dam Game #5 (days)	N/A	140.50	52.33	N/A
Dam Game #6 (days)	N/A	N/A	87.00	N/A
Dam Game #7 (days)	N/A	N/A	97.00	N/A
Mean project length – Canal	**249.39**	**261.61**	**318.60**	**126.08**
Canal Game #1 (days)	245.29	254.87	304.37	182.26
Canal Game #2 (days)	248.67	266.77	327.27	119.56
Canal Game #3 (days)	309	297.52	330.44	0
Canal Game #4 (days)	N/A	211.29	406.75	0
Canal Game #5 (days)	N/A	196.50	0	N/A

Table 9.2: ACPM Overview statistics by year

9.4.1 Year 1 - Academic Year 2005/2006

Note that for this initial year of results additional explanation and detail has been added including some analysis of example students from the year. Similar analysis has been carried out for other years with similar results. These are not included in the thesis due to a lack of space.

9.4.1.1 Muck Game

Table 9.3 shows the overall averages for the variables and information for all the students using the Muck Game in this initial year of operating the ACPM module. It compares all games played, completed games only and games with significant progress. In total 64 runs of the Muck game were attempted by all 16 students with 41 games fully completed.

Variable	Statistic	All players	>5% Progress completed	Completed Games only
Time Spent	Mean	315.89	335.64	368.48
	St Dev	236.33	231.89	239.63
	Min	0.92	58.48	58.48
	Max	1116.02	1116.02	1116.02
Project Duration	Mean	138.34	149.60	148.38
	St Dev	64.93	54.01	35.51
	Min	0	11	106
	Max	251	251	236
Project Spend	Mean	2,068,393	2,237,043	2,300,399
	St Dev	1,832,514	1,807,732	2,071,500
	Min	0	285,797	1,384,612
	Max	13,639,304	13,639,304	13,639,304
Number of Plans made	Mean	4.45	4.78	4.81
	St Dev	3.28	3.19	2.94
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	-740,760	-801,006	-613,542
	St Dev	1,719,864	1,762,910	2,071,552
	Min	-11,949,304	-11,949,304	-11,949,304
	Max	305,388	305,388	305,388
Daily Spend	Mean	13813	14,512	14,588
	St Dev	7163	6,680	7,767
	Min	0	7,741	8,300
	Max	57,794	57,794	57,794

Table 9.3: Statistical results from use of Muck Game in academic year 2005/2006

From the breakdown by run number (Table 9.4), it is possible to say that improvement in completing the simulation is occurring. The statistics shown in both tables 9.3 and 9.4 confirm the qualitative observation made regarding the ability of the student's taking the module in its initial year (see section 8.3.2). Performance was of a generally high standard with a high percentage of the students running and completing the game.

The dataset is highly scattered with many of the variable's having relatively high standard deviation values. This is particularly evident for *TimeSpent, ProjectSpend* and *Profit* which all have standard deviations comparable to or higher than the mean values for those variables.

A full table containing variables for the Muck game is included in the e-appendices CD attached as an excel format spreadsheet. There is insufficient space to list all the 64 student runs here or in the printed appendices. A selection of this data is shown in table 9.5 for the purposes of discussion.

variable	Statistic	Run 1st	2nd	3rd	4th
Number of players	Started	18	16	16	14
	Finished	7	11	8	11
	%Complete	38.9%	64.7%	50%	78.6%
Time Spent	Mean	360.39	299.13	299.35	297.93
	SD	277.64	157.69	216.06	267.54
	Min	4.52	22.80	68.78	0.92
	Max	1027.17	555.12	805.20	1116.02
Project Duration	Mean	131.94	162.88	138.35	118.50
	SD	83.86	58.39	46.22	53.90
	Min	0	10	27	0
	Max	251	251	218	251
Project Spend	Mean	2,024,567	2,747,991	1,806,774	1,665,739
	SD	1,521,506	2,930,465	684,104	1,206,877
	Min	0	150,633	315,437	0
	Max	6,085,487	13,639,304	3,340,315	5,572,440
Number of Plans made	Mean	4.94	5.44	3.41	3.93
	SD	3.69	3.24	2.35	3.28
	Min	0	1	1	0
	Max	10	10	9	10
Overall Profit	Mean	-997,592	-1,262,179	-394,510	-235,085
	SD	1,116,142	2,845,222	676,850	1,146.907
	Min	-4,395,487	-11,949,304	-2,040,315	-4,321,940
	Max	48,856	220,862	279,671	305,388
Daily Spend	Mean	14,113	15,748	13,026	12,171
	SD	6,964	11,045	1,970	4,497
	Min	0	8300	10,783	0
	Max	26,006	57,794	19,197	22,201

Table 9.4: Muck game statistical data for academic year 2005/2006 grouped by run

Table 9.5 shows data for 19 runs for 5 students, 2 of whom completed all four runs of the game. All students shown managed to complete the game at least twice with all but one of the students, user NHPT, making an overall profit on constructing the Dam (fixed income for completing the project is $1.69M).

The students shown in table 9.5 were selected at random and therefore might be considered to be representative of the performance of the overall intake of students for this year. There is a fairly wide variation in completion times with a general trend for a reduction in completion times, both for time played *(time)* and simulated project duration *(days)* with repeated runs. None of the students shown are able to complete the project without significant financial losses in the first instance. The performance of each student shown will now discussed in more depth to illustrate what can be learnt from the small set of key variables listed in the table and this will be supplemented by additional data to back up any hypotheses.

User	Play	Start	Finish	Time	Days	%Done	Plan Spend	Actual Spend	Plans
ISHW1	1	09/02/06	22/05/06	1027	234	100	171533	6085487	10
ISHW2	2	02/03/06	07/03/06	316	131	100	1900000	1863736	7
ISHW3	3	15/03/06	21/03/06	307	106	100	1511882	1505976	5
ISHW4	4	21/03/06	23/03/06	353	115	100	1541109	1538686	8
MEGO1	1	09/02/06	18/03/06	813	135	75	1118571	2097000	3
MEGO2	2	19/02/06	09/03/06	363	67	41	767374	900653	3
MEGO3	3	08/03/06	27/05/06	805	142	100	1600000	1637973	1
MEGO4	4	11/03/06	16/03/06	122	114	100	1485417	1487597	1
MNPO1	1	09/02/06	17/03/06	613	202	100	1650000	2466356	6
MNPO2	3	09/03/06	22/03/06	660	116	100	1600000	1591268	3
MNPO3	3	22/03/06	22/03/06	371	152	83	1597059	2030374	3
NHPT1	1	09/02/06	02/03/06	484	168	100	1860000	2139070	4
NHPT2	2	02/03/06	08/03/06	407	167	100	1820000	1780776	6
NHPT3	3	09/03/06	24/05/06	185	144	100	1600000	1788014	1
NHPT4	4	16/03/06	16/03/06	171	144	100	2100000	2070083	6
OYZP1	1	09/02/06	09/03/06	92	32	20	262500	746617	1
OYZP2	2	09/03/06	23/03/06	442	172	90	2200000	2363635	7
OYZP3	3	21/03/06	22/03/06	58	107	100	1400000	1428897	2
OYZP4	4	22/03/06	23/03/06	212	107	100	1400000	1489523	1

Table 9.5: Selected data from Muck Game students in academic year 2005/2006

As an example for one student of what can be seen from the data in table 9.5, ISHW completed all four runs provided in numerical order (1-4). The student spent approximately three times longer on their initial attempt than subsequent runs and the project duration was more than double that of the later attempts. Actual spend was between 3 and 4 times greater in completing this first attempt compared to later attempts. Their performance in relation to planned spend versus actual spend was very poor in the initial attempt (planned spend of 1.7M and actual spend of 6.1M which was the highest of all shown in the table). Later attempts saw planned and actual spend values being almost equal (actually a small profit was made in all instances). The student sent a number of messages to the fictional head office for ISHW1 which are shown in table 9.6. These give some insight into the student's impression of their performance and the queries they had in relation to the simulated project. It shows that the student was immersed in the simulation; analysing numbers; learning; asking questions.

In terms of performance based on the statistics shown in table 9.5, ISHW3 showed the best overall performance (shortest duration, fastest completion, highest profit, lowest amount of re-planning and a negligible difference between planned and actual spend) with ISHW4 being a very close second place. It is not evident from these statistics why the performance at the 4th run is slightly inferior to the 3rd. It may be due to an unforeseeable event within the simulation such as an accident or fine. It could also be due to random variations such as weather conditions or equipment reliability. It may also be that the student had reached a satisfactory level of performance and was experimenting with other simulated options in the final run.

Memos to Head Office from ISHW1 re: Dam Project	
16/02/2006 12:45:26	Site is looking more controlled at the moment. Suffering with the early expenses but balancing the resources to speed up rock output as it looks to be hampering the progression of the clay. May be looking at an above budget project. Look at making up in possible claims!!??
16/02/2006 12:57:04	*After monitoring the sites income over a period of 10 weeks it has become apparent that the 90% immediate payment for each meter [sic] of rock and clay complete is not being received or at least documented in the period reports. Could you please chase payment or offer reasons why the client is withholding more than the 10% documented in the contract. Regards Roy*
16/02/2006 13:32:17	*Fear the bad weather is coming. Will continue for as long as possible but once progress is significantly below 1m per week in rock and clay work will stop. Have the luxury of 15 weeks to complete remaining 8m, however quantity of work per meter is increasing as the length of the clay haul road. Rainfall will be crucial now. We are may pay dearly for the slow start. Regards Roy*
01/03/2006 18:28:30	*Project completed over budget and time. Records have been taken, revision done and lessons learnt. The next project is expected to go better. More consideration will be given to weather and plant productivity as well as ensuring the project is completed on time. In this project work was stopped in bad weather and the site allowed to deteriorate, in the future it is thought that carrying on with the work using a greater number of plant will be the way forward as late completion penalties have cost us dearly in this project. Towards the end of this project it was felt that the planning was being brought under control and it is felt that the next project will be planned in 5 week periods allowing for extra planning if an unforeseen event occurs.*

Table 9.6: Messages sent to simulated head office from player ISHW1

Figure 9.1 shows progress against date of start and finish for the sample student population. The graph shows some overlap between runs of the game for individual students and it appears that students are often working concurrently on separate runs of the game. More detailed analysis of the umpire data files (included in the e-appendices) shows that the degree of concurrent operation is much less than apparent as some of the activity on those extended runs (e.g. ISHW1, MEGO1, NHPT3) is the student logging into the simulation to review their play after completion.

A clustering of runs of the users combined with an increased rate of progress (indicated by the gradient of the line) is clearly evident from 06/03/06 to 20/03/06. Prior to 06/03/06 there are fewer runs in operation and the rate of progress is much slower. The coursework element of the assessment for the module was due around the end of March and the pattern of increased play at increased intensity between 06/03/06 and 20/03/06 is due to the approach of the coursework submission date. Once coursework has been submitted there is little activity with only three of the five students using the games after this point.

This pattern of use for the game is very typical and reflects the general work method of the students – leaving coursework until close to the deadline.

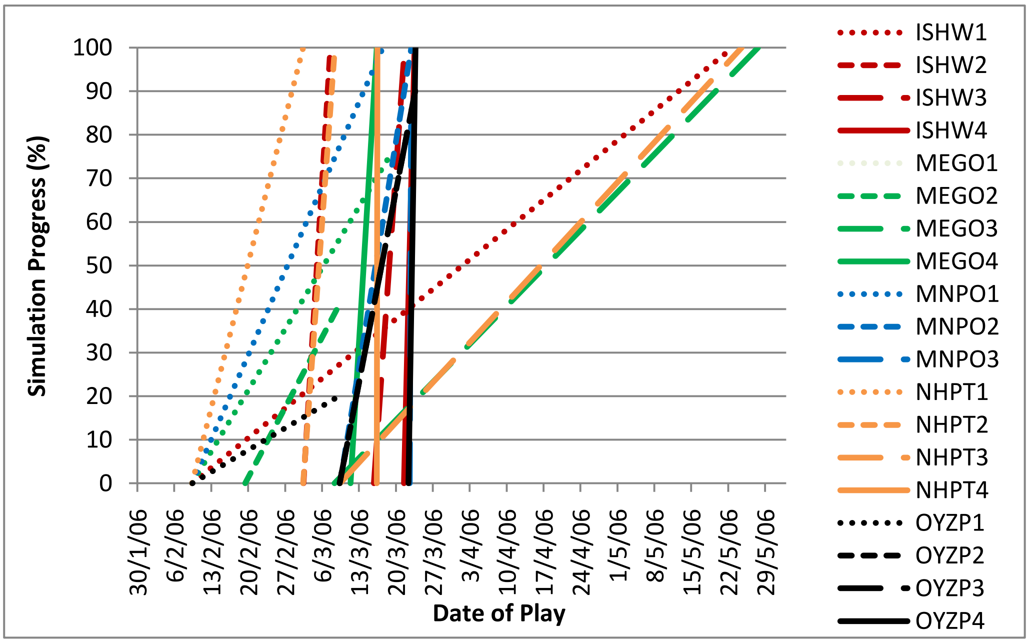


Figure 9.1: Timeline of Muck Game progression for sample student population

In terms of the sample student population, figure 9.2 and 9.3 show variable values for all runs of the game. The relationship between poor financial performance and poor performance to plan can be clearly seen in figure 9.2 where the spikes in maximum summary measure coincide with a significant financial loss. With the exception of NHPT, the students show improved profit with repeated play as would be expected. NHPT is also the only student to not make a profit on the construction of the Dam on any of their runs of the game though their performance is more consistent across all runs of the game that the other students (mainly due to a lack of improvement) and their summary measure is low across all runs in comparison to the other students.

Figure 9.3 confirms the performance indicated in figure 9.2 by displaying the daily spend and daily percentage progress for the example students. From this it can be seen that the performance problems for NHPT are related to a lack of daily progress and low daily spend. Analysis of the data files for this user confirm this and it seems likely that they have deliberately adopted a ‘slow but steady’ strategy for completing the simulation within the specified constraints

This sort of analysis is used in chapter 10 to enable more detailed conclusions to be drawn about the learning styles and in-game behaviour of the students in relation to the research aims of the work.

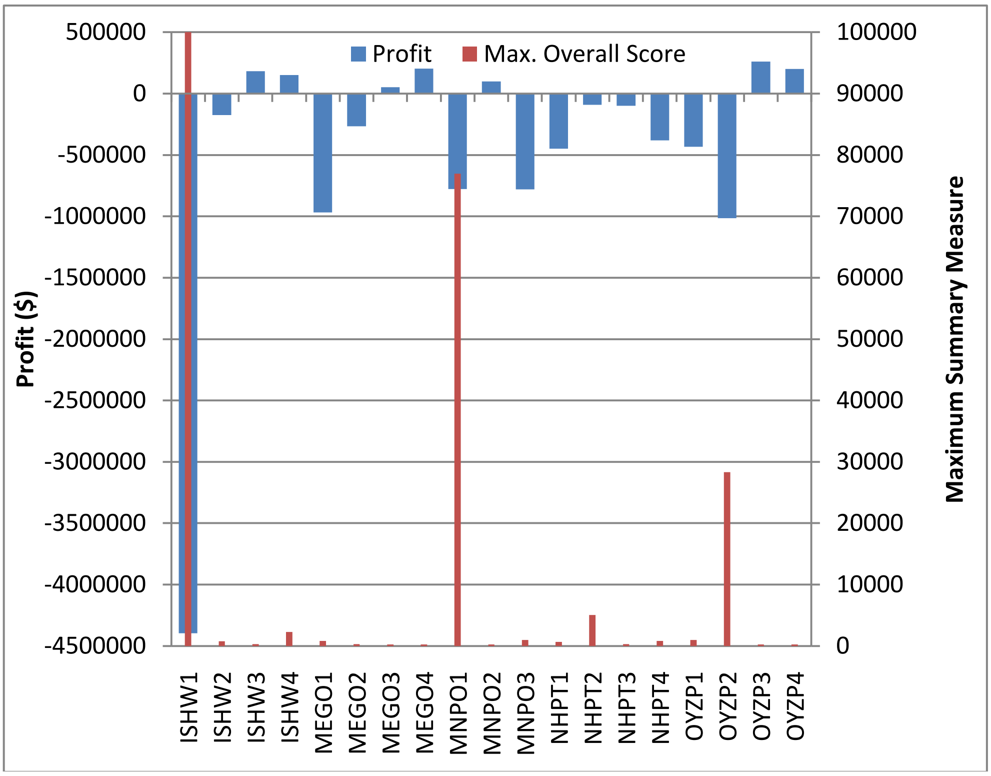


Figure 9.2: Chart showing profit and maximum overall score for sample students

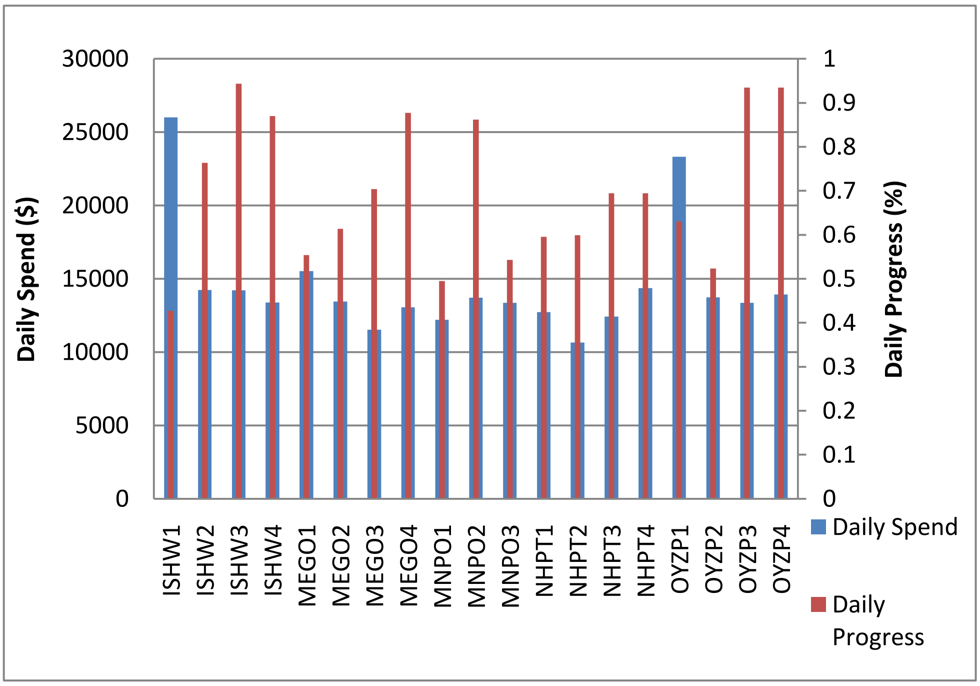


Figure 9.3: Daily spend and progress for sample student population

9.4.1.2 Canal Game

variable	Statistic	All players	>5% Progress completed	Completed Games only
Time Spent	Mean	184.09	214.66	211.23
	St Dev	169.92	176.71	102.71
	Min	0.37	28	118.43
	Max	726.62	726.62	443.82
Project Duration	Mean	249.72	320.50	378.63
	St Dev	194.23	158.28	128.23
	Min	0	42	238
	Max	631	631	631
Project Spend	Mean	4,458,145	5,709,044	7,360,617
	St Dev	3,973,976	3,613,250	3,689,047
	Min	0	473,940	4,684,361
	Max	15,330,283	15,330,283	15,330,283
Number of Plans made	Mean	3.22	3.93	5.25
	St Dev	3.30	3.36	3.92
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	25,910	38,099	439,383
	St Dev	2,448,100	2,799,335	3,689,047
	Min	-7,530,283	-7,530,283	-7,530,283
	Max	3,115,640	3,115,640	3,115,640
Daily Spend	Mean	15,571	17,162	18,898
	St Dev	9,779	4,524	3,552
	Min	0	11,284	14,731
	Max	40,000	24,451	24,295

Table 9.7: Statistical values for students using the Canal Game in first year of operation

Data from the Canal Game for this initial year of running the ACPM module is shown in tables 9.7 and 9.8 in an identical format to that provided in the previous section for the Muck Game. Low usage of the Canal Game in this initial year makes it difficult to be certain of any conclusions from the data shown in either table. This is especially true for Table 9.8 due to the very low numbers of students who attempted more than one run of the Canal Game.

With only three students attempting more than one run of the Canal Game in this year, data shown in table 9.8 is of quite limited use but has been included here for the sake of completeness and consistency rather than for its utility in the analysis. This lack of use of one of the games made it difficult to draw conclusions about any transfer of learning between projects in this initial year. It led to changes in the data and operation of the module and the resulting learning is discussed in chapter 10.

The data in figure 9.4 gives a timeline of player use of the Canal Game for all students attempting the game in this year. It shows similar attributes to that of the sample students from the Muck Game shown in figure 9.1. For example, in figure 9.4 it can be seen that the runs cluster around the coursework deadline again.

variable	Statistic	Run 1st	2nd	3rd
Number of Players	Started	14	3	1
	Finished	6	1	1
	%Complete	42.9%	33.3%	100%
Time Spent	Mean	200.25	123.82	138.78
	SD	188.55	77.62	0
	Min	0.37	49.03	138.78
	Max	726.62	204	138.78
Project Duration	Mean	245.71	248.67	309
	SD	218.41	93.47	0
	Min	0	141	309
	Max	631	309	309
Project Spend	Mean	4,616,512	3,642,691	4,687,365
	SD	4,472,567	1,735,454	0
	Min	0	1,644,589	4,687,365
	Max	6,937,500	4,774,002	4,687,365
Number of Plans made	Mean	3.36	3.33	1
	SD	3.67	1.53	0
	Min	0	2	1
	Max	10	5	1
Overall Profit	Mean	-401,584	991,975	3,112,635
	SD	2,483,525	1,845,996	0
	Min	-7,530,283	-577,089	3,112,635
	Max	3,115,640	3,025,998	3,112,635
Daily Spend	Mean	15,911	14,116	15,169
	SD	11,124	2.127	0
	Min	0	11,664	15,169
	Max	40,000	15,450	15,169

Table 9.8: Canal game data for academic year 2005/2006 grouped by run number

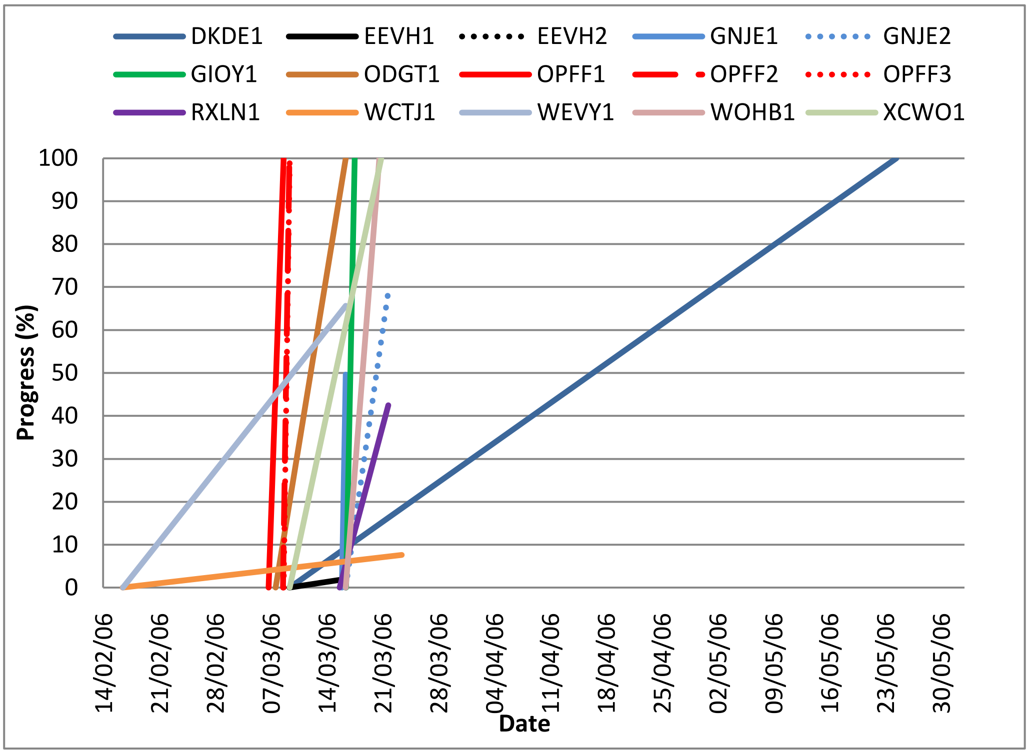


Figure 9.4: Chart showing timeline of gameplay and progress for all Canal Game players in academic year 2005/2006

The majority of time spent by the students using the Canal game was during March 2006 as can be seen from Table 9.9 which lists user statistics for all Canal game users in this academic year. Eight out of the eighteen runs of the Canal game resulted in completion, around 45%. Three students reached their second run with only a single student (user OPFF) completing the second (and also third) runs.

Fourteen of the sixteen students taking the module played the Canal game in this year. In total, eight games were completed by six individual students. An anomalous value for the variable *PlannedSpend* is noted for user WOHB1 in red in table 9.9. This figure is far too low to be an accurate value and is thought to have been due to an error, either in writing the data to the umpire data file or in calculating the value in the Muck Game. This error would not have been evident to the student as this variable is only in the umpire data file and not in the player data files.

User	Time (s)	Project Days	%Done	Planned Spend	Actual Spend	Income	Plans	Daily Progress	Profit
DKDE1	9692	625	100	6,700,000	1,533,0283	7,800,000	10	0.16	-7,530,283
EEVH1	11515	8	2	209,000	320,000	253,000	3	0.25	-67,000
FDED1	22	0	0	0	0	0	0	0.00	0
GNJE1	8753	308	50	3,400,000	4,308,537	3,596,500	4	0.16	-712,037
GOIY1	11466	318	100	6,080,000	6,215,176	7,800,000	1	0.31	1,584,824
MKVH1	6825	0	0	0	0	0	0	0.00	0
ODGT1	26629	495	100	6,937,500	9,317,066	7,800,000	6	0.20	-1,517,066
OPFF1	14216	318	100	4,977,777	4,684,361	7,800,000	1	0.31	3,115,640
QLKI1	142	0	0	0	0	0	0	0.00	0
RXLN1	43597	145	43	3,702,500	3,545,414	3,079,000	1	0.29	-466,414
WCTJ1	1680	42	8	1,575,000	473,940	649,000	1	0.18	175,060
WEVY1	9713	526	66	6,800,000	6,559,710	4,631,500	2	0.12	-1,928,210
WOHB1	10043	411	100	12,784	8,558,888	7,800,000	10	0.24	-758,888
XCWO1	13913	238	100	5,847,002	5,317,799	7,800,000	8	0.42	2,482,201
EEVH2	2942	141	14	2,706,667	1,644,589	1,067,500	2	0.10	-577,089
GNJE2	12240	296	70	5,933,333	4,509,483	5,036,500	3	0.23	527,017
OPFF2	7106	309	100	4,784,323	4,774,002	7,800,000	5	0.32	3,025,998
OPFF3	8327	309	100	4,723,810	4,687,365	7,800,000	1	0.32	3,112,635

Table 9.9: Results and data from Canal Game for academic year 2005/2006

9.4.2 Analysis of data from years 2, 3 and 4

Data equivalent to that provided in tables 9.3-9.4 and 9.7-9.8 for years 2, 3 and 4 are included in the appendices (appendix I) as there is no space to include all the data here in the main body of the thesis. From these it will be seen that:

- The general performance was similar although the number of students varied.
- There was a significant difference in the use of the Canal game (as mentioned in section 9.4.1). This was partly due to an improvement in the IT problems encountered in the initial year but also because of the staff encouraging the students to play it. Without the Canal game, the students

would not be able to learn the difficulties and benefits of transferring management data between projects,

- Some of the figures from years 3 and 4 are not directly comparable with each other and previous years (e.g. average profit). This is because the project parameters were changed to ensure that the students were not able to manage their projects to a 'trivial scenario' in which the true impact of weather on the simulated project could be removed.

Points of interest relevant to each game will now be described.

9.4.2.1 Muck Game results from years 2, 3 and 4

Some of the key points identified from analysis of the Muck Game data collected in years 2, 3 and 4 are:

1. The increased difficulty in years 3 and 4 in the Muck Game from changes to project start dates were overcome by some students on repeated runs of the game despite early feedback from students stating that it was impossible to make a profit on the project. This can be seen more clearly from the bar chart shown in figure 9.5, though only a single student managed to make a profit in year 3. There is however a significant decrease in profitability, as intended by the changes to the simulations.
2. Despite the increased difficulty in completing the Muck Game profitably, the completion rate was higher in years 3 and 4 than in year 2. This could simply be due to the greater staff/student ratio in years 3 and 4. However, it could be that the increased difficulty provided greater challenge for students to complete the game to a satisfactory level of performance thereby increasing engagement with the game.

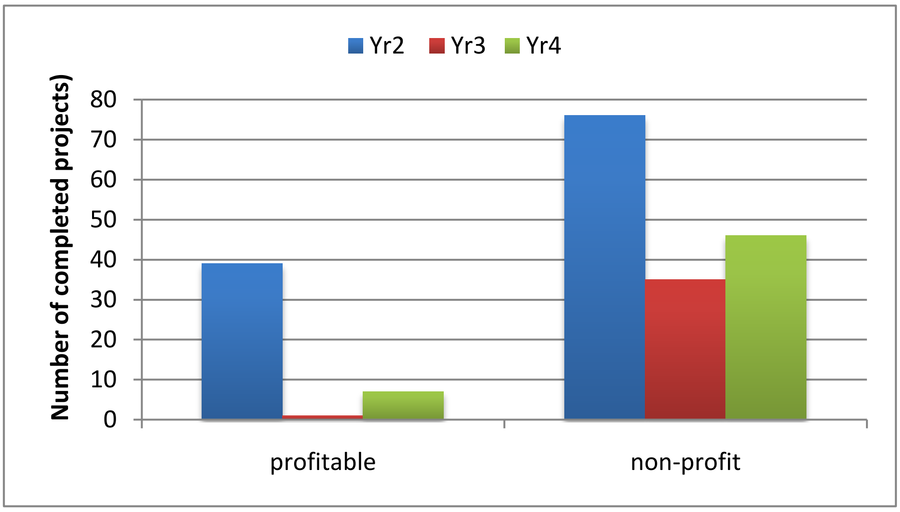


Figure 9.5 : Number of profitable and unprofitable simulated projects for years 2-4 (completed Muck Games only)

3. In terms of time spent on the Muck Game by students there was a greater average time spent in year 2 than in years 3 and 4 which were broadly comparable across all three categories shown in the bar chart in figure 9.6. This may be due to the changes in the module in years 3 and 4 which reduced the overall class time spent focussing on running the games. The technical problems in year 4 could also have limited the students' potential time available to run the simulations.
4. As seen in figure 9.6, average project durations were lowest in year 2. The simulation settings in year 2 meant that students could more easily complete the project prior to the onset of poor weather reducing the project duration.

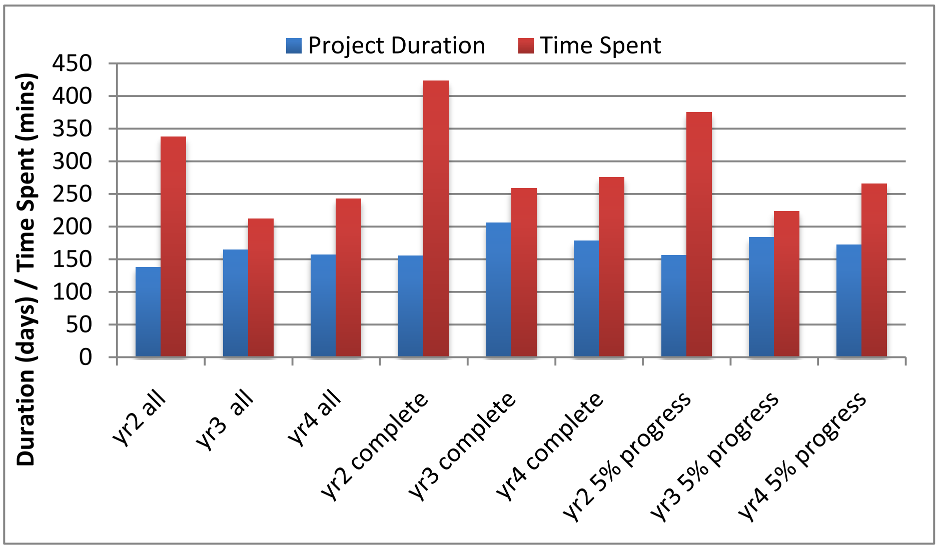


Figure 9.6 : Average time spent and project duration for Muck Game in years 2-4

9.4.2.2 Canal game results from years 2, 3 and 4

As stated earlier in the chapter the Canal Game was more widely used in years 2 and 3 than in years 1 and 4. The points made here are therefore more representative of the use of the Canal game in the ACPM module than those provided in the description of its use in year 1 (section 9.4.1.2). Specific findings of interest are as follows:

1. With the exception of a small number of instances, the Canal game is played after a student has gained significant experience with the Muck game.
2. In year 3 the number of students playing both games was of the same magnitude. In other years more students played the Muck game than the Canal game.
3. Time spent on completing the Canal Game was broadly similar on average in all three years as can be seen in figure 9.7. Overall time spend

by all attempts at the game was, on average, much lower in year 4 than the other years and project duration was similarly reduced. This is likely to be due to the decrease in use of the Canal game in year 4.

4. It shows that not only did fewer students use the Canal Game but those that did use it played it less overall.

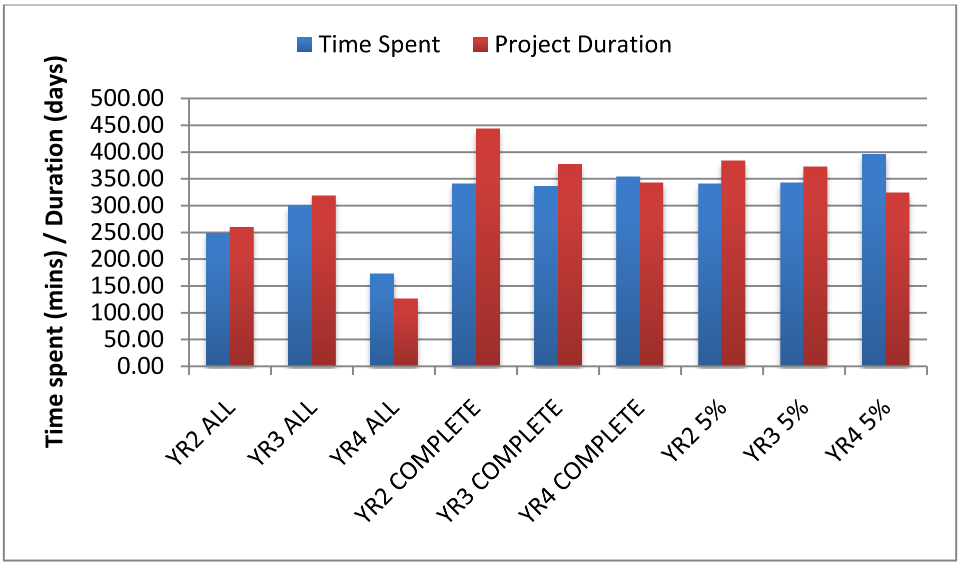


Figure 9.7 : Average time spent and project duration for Canal Game in years 2-4

5. From figure 9.7 it is evident that for those students getting past the initial 5% of progression, the time spent was almost identical in years 2 and 3 and slightly increased in year 4. The reduction in time spent overall for year 4 is therefore caused by students who do not make a significant attempt at running the simulation game.

6. As expected the profitability of Canal projects is substantially higher than the results for the Muck Game with the majority of the projects being profitable in all three years. This can be seen in figure 9.8.

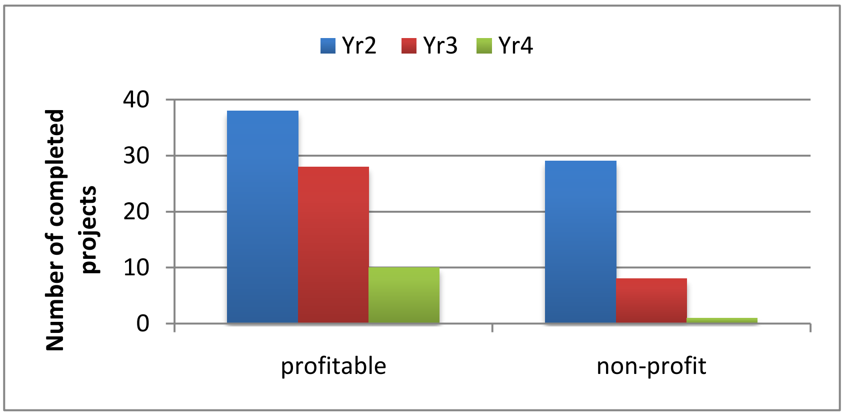


Figure 9.8 : Bar chart of showing profitability of Canal Game projects in years 2-4

7. As seen in figure 9.8, the relative number of profitable projects in years 3 and 4 is higher than year 2. This is not simply due to changes in the simulation settings. Changes made to the simulation in year 4 increased the difficulty by starting the project at the start of the rainy season whilst maintaining the same climate conditions as year 2. This anomaly may be due to the lower number of players in year 4 biasing the results. It is likely that it was only the more engaged and committed students who played the game in year 4.

9.4.2.3 Examination of relationship between in-game variables and student assessment marks

Changes to monitoring and tracking procedures after the initial year of operation made it possible to compare the results of formal assessment of the students during the ACPM module (through examination and coursework) with their in-game performance. Various graphs plotting student assessment marks against the primary variables relating to game performance (Summary Measure and Profit) were created and examples of these are shown in figures 9.9-9.11. In order to produce it was necessary to plot each student's assessment mark against a single value representing their best performance at playing each game. A number of potential automated methods were tested for this purpose but it was determined that the optimum method for choosing the *best* run of the game was manually. This was carried out for the dataset for year 2 of operation which represented the largest and most diverse set of data for both games.

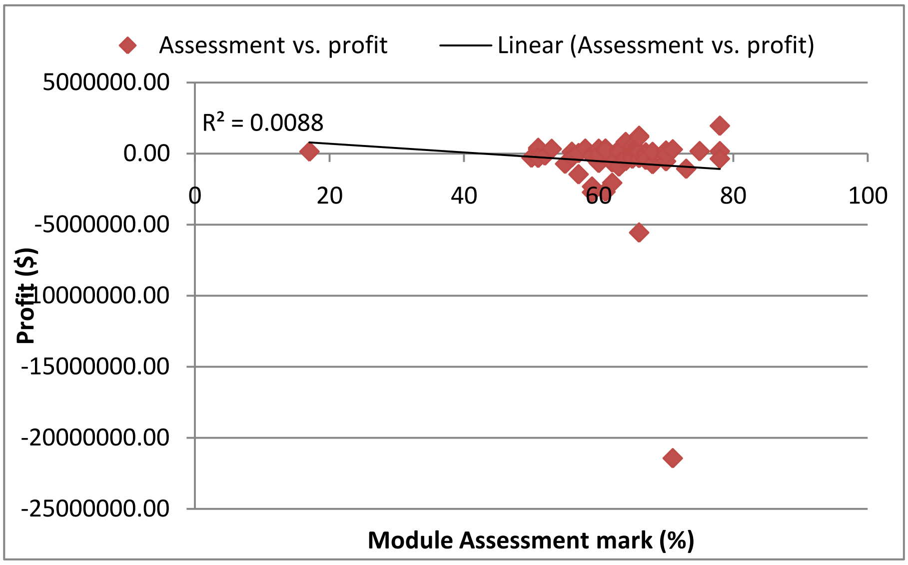


Figure 9.9 : Chart plotting module assessment mark against simulated profit for 'best' run of the Muck Game in year 2 (academic year 2006/2007)

Figure 9.9 compares the each student's final mark for the module with the profit generated in their best run of the Muck game. As with all the charts in this section, a line has been drawn through the scattered data to identify any potential linear relationships. The value of the coefficient of determination ($R^{2)}$ has been added to show the strength of any relationship between the points plotted. Values can lie between 0 and 1.0 where the latter indicates that the regression line perfectly fits the data. The extremely low value of R^2 in figure 9.9 tends to indicate that there is no significant linear relationship between student's assessment marks and the profit generated in their best attempt at the Muck game. Outliers were removed to see if they were distorting the result of the analysis and obscuring any potential relationship between assessment marks and in-game performance. The result of this is shown in figure 9.10. Although the value of R^2 is greatly increased it is still too low to represent a clear relationship between the two parameters.

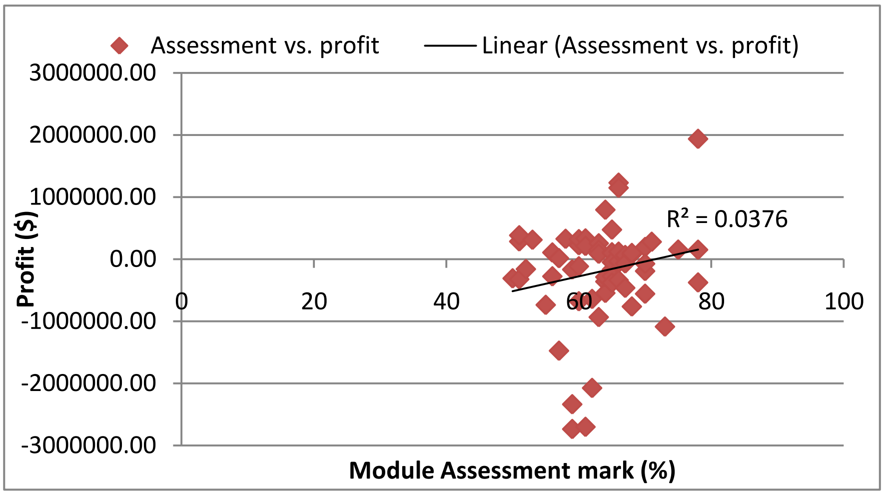


Figure 9.10 : Module assessment mark against simulated profit for 'best' run of the Muck game in year 2 with outlier data removed

Figures 9.11 shows a similar graph comparing total assessment marks and summary measure for the Muck Game. Figure 9.12 shows a comparison of assessment marks and game performance measures for the Canal game. In both graphs the same result is found with there being no identifiable relationship established.

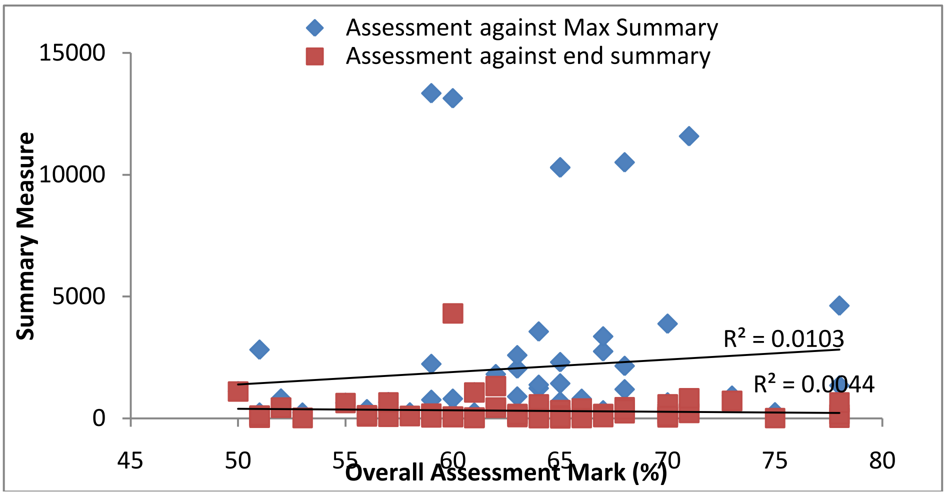


Figure 9.11 : Chart plotting in-game summary measure against assessment marks for 'best' run of Muck Game for students in year 2 (2006/2007)

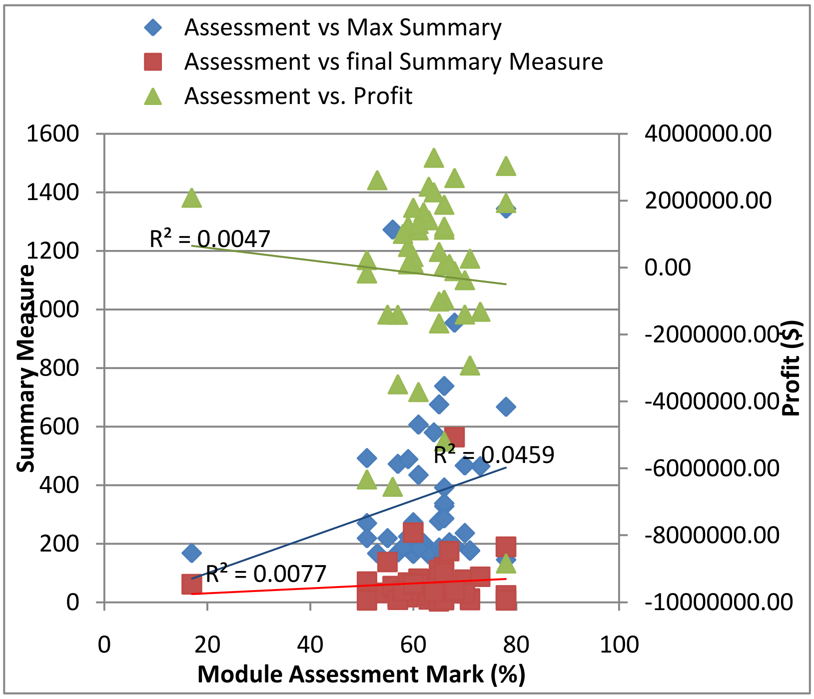


Figure 9.12 : Chart showing relationships (or lack of) between module assessment and in-game performance for 'best' runs of Canal Game in year 2

In all the graphs shown, the relationship between a student's formal assessment mark and their in-game performance has been shown to be non-existent or extremely weak. This was not unexpected and there are a number of reasons why this type of analysis will fail to make any connection between performance at the games and performance in completing coursework and examinations. These include:

- Inherent issues in blended learning as highlighted in chapter 2 mean that it is often difficult to directly compare the heterogeneous aspects of a blended learning experience. This is simply a limitation of blended learning that can be mitigated but never eliminated.

- Uncertainty that actual student comparison is accurate. A major issue when using e-learning in an unsupervised environment is the difficulty in ensuring that any student data collected is definitively linked to the specific student. Without the presence of teaching staff to ensure that the student tracked is the one logged into the game there is no way to be sure that students are not sharing, swapping or stealing the user details for other students.
- The use of group working in the games is both documented and encouraged since it has been seen to improve overall student learning. It does however make it difficult to ascribe game performance (which could be the product of a group of students) to a single student's performance at the assessed requirements of the module.
- It is well known that some types of learner show higher than average aptitude at examination type testing. These students will be likely to perform better in the examination aspect of the module than their game performance may imply.
- The teaching constraints of the module imposed by accreditation bodies and the academic institution meant that the students have to be provided with a full set of traditional teaching materials in addition to the simulation games. It is quite possible for students to choose to play either of the games once and perform badly whilst still performing well in the assessed elements.

9.5 Overall ACPM dataset & statistics

In this section data from all four years of running the ACPM is combined and analysed. This larger dataset has the potential to be a useful tool in the assessment of student performance at the game by providing some baseline measures of performance and typical ranges for variables. By combining the data from all years of operation, the vagaries specific to a given year such as a reduced use of the Canal Game due to IT problems are mitigated to some degree. The increased population for generating statistical measures also gives greater value to those measures and reduces the effects of outliers.

Full datasets for each game will be discussed in turn using tables and graphs in a similar way to the analysis provided for the initial year of operation (see section 9.4.1) in the following sections.

9.5.1 Muck Game

variable	Statistic	All players	>5% Progress completed	Completed Games only
Number of Players	Started	415	371	241
	Finished	241	241	241
	%Finish	58.07	64.96	100
Time Spent	Mean	297.08	324.39	357.92
	SD.	295.11	296.99	334.03
	Min	0.07	3.70	18.50
	Max	2882.40	2882.40	2882.40
Project Duration	Mean	145.61	162.54	167.02
	SD	75.41	60.44	44.55
	Min	0.00	11.00	106.00
	Max	251.00	251.00	251.00
Project Spend	Mean	2,564,898	2,865,285	3,296,855
	SD	3,345,920	3,416,310	4,076,891
	Min	0	151,781	1,305,886
	Max	30,323,691	30,323,691	30,323,691
Number of Plans made	Mean	3.79	4.19	4.13
	SD	3.07	2.98	2.87
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	-1,286,290	-1,436,974	-1,608,158
	SD	3,189,440	3,341,329	4,076,738
	Min	-28,633,691	-28,633,691	-28,633,691
	Max	384,114	384,144	384,114
Daily Spend	Mean	14,977	16,427	17,883
	SD	12,913	12,798	15,469
	Min	0	7,093	8,300
	Max	120,812	120,812	120,812
Maximum Summary Measure	Mean	5,929	6,402	5,521
	SD	21,423	22,220	13,678
	Min	0	198	198
	Max	292,476	292,476	87,959
Final Summary Measure	Mean	809	866	685
	SD	2,944.18	3,055	3,249
	Min	0	2	6
	Max	47,615	47,615	47,615

Table 9.10: Muck Game statistics for all ACPM data collected

Table 9.10 shows statistics for all players of the Muck Game in the first four years of operation and is broken down into three groupings; all students who logged into the game, students who reached more than 5% progress and students who completed the simulated project. This separation of statistics enables the analysis of the various variables for differing purposes. For example, it is useful to be able to compare average time spent playing the game to completion in comparison to the average time spent for all those attempting the games. Also, it is of interest to note the minimum and maximum times spent for completed games with a student managing to complete the Muck game is just over 18 minutes whilst another spent just over 48 hours to reach the same point.

Analysis of the full set of data verified a number of potential relationships between variables that been identified in looking at the yearly data in isolation. Some of the more evident, significant and relevant will now be described and illustrated with appropriate graphs, charts and tables,

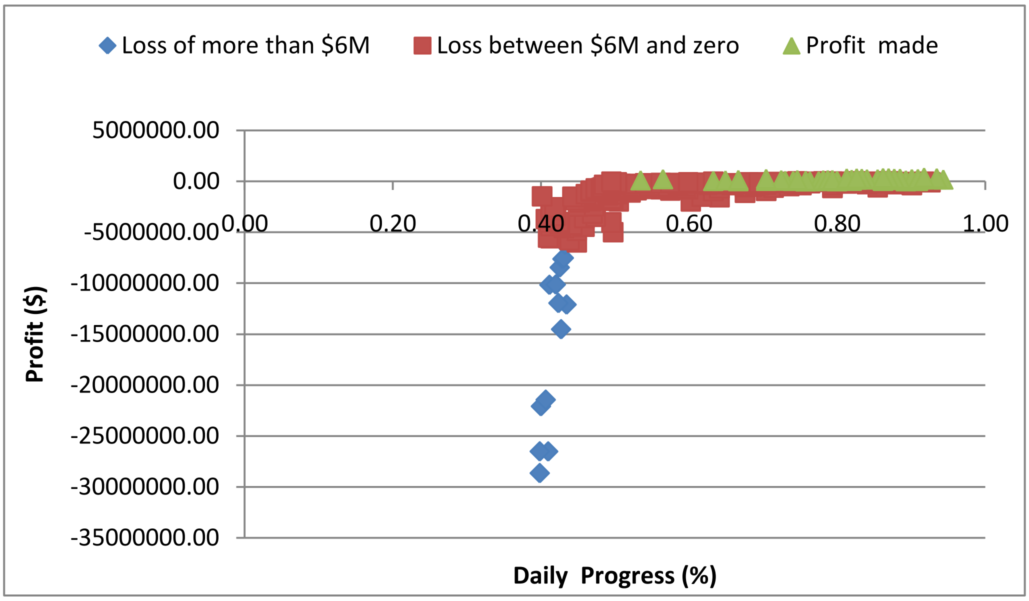


Figure 9.13 : Links between rate of progress and overall profit in completed runs of Muck Game

Figure 9.13 shows a graph of profit compared with daily rates of progress for all the data collected from the Muck game. Data has been plotted into three specific groupings; those making a huge financial loss, those showing a loss of $6M or less and those making a profit. It can be seen that there is a definite link between the daily spend and the final profit. This is not surprising since income is fixed but it could prove useful in assessing a student's financial performance during play. Student's progressing at 0.4-0.5% progress per day will not be able to produce a profit. Those progressing at 0.8% progress per day are highly likely to be profitable. This result could be used in future work to automatically predict student performance, alerting the tutor to those performing poorly. This is discussed further in chapter 11 under future work.

9.5.1.1 *Breakdown and analysis of data by each iteration of simulated play*

variable	Statistic	Run 1st	2nd	3rd	4th	5th	6th
Number of Players	Started	132	115	96	64	5	2
	Finished	61	69	69	40	2	0
	%Finish	46.21	60.00	71.88	62.5	40.00	0
Time Spent	Mean	345.40	283.78	310.45	199.51	453.55	100.58
	SD.	282.51	246.93	360.84	204.50	658.90	92.74
	Min	0.12	0.73	0.25	0.07	10.42	7.83
	Max	1874.42	1935.1	2882.40	1116.02	1762.80	193.32
Project Duration	Mean	157.56	157.39	144.15	109.14	87.60	87.00
	SD	85.04	71.24	58.60	70.27	70.32	51.00
	Min	0	0	0	0	0	36.00
	Max	251	251	250	251	156	138.00
Project Spend	Mean	3,174,402	3,003,155	2,051,900	1,481,078	1,020,157	1,012,171
	SD	4,090,808	4,157,446	1,302,006	1,198,690	820,055	685,138
	Min	0	0	0	0	0	327,033
	Max	30,323,691	28,197,628	9,313,812	7,221,711	1,868,982	1,697,309
Number of Plans made	Mean	4.83	4.03	3.02	2.73	0.80	1
	SD	3.38	2.94	2.39	2.79	0.40	0
	Min	0	0	0	0	0	1
	Max	10	10	10	10	1	1
Overall Profit	Mean	-2,009,470	-1,665,695	-603,072	-276,699	-113,636	-328,671
	SD	3,861,021	4,026,033	1,164,731	916,865	180,137	73,138
	Min	-28,633,691	-26,507,628	-7,623,812	-5,531,711	-381,379	-401,809
	Max	195,022	251,137	384,114	333,219	66,058	-255,533
Daily Spend	Mean	16,544	16,592	13,301	12,011	8.963	10,692
	SD	15,933	15,954	5,057	5,824	4,642	1,608
	Min	0	0	0	0	0	9,084
	Max	120,812	115,564	39,973	29,597	12,992	12,299
Maximum Summary Measure	Mean	10,727	4,419	4,758	1,774	909	2,598
	SD	35.460	10,044	12,758	2,914	1,350	1,785
	Min	0	0	0	0	0	812
	Max	292,476	63,995	78,372	12,409	3,596	4,283
Final Summary Measure	Mean	1,312	880	460	290	151	1,039
	SD	2,912	4,514	774	497	104	227
	Min	0	0	0	0	0	812
	Max	21,897	47,615	3,622	2,727	323	1,266

Table 9.11: Muck game statistics by run for all ACPM Data

Table 9.11 shows the full set of Muck Game data broken down by run number. In this case the entire set of data was used with no exclusion of data from incomplete runs or those with less than 5% completion. Details of 5th and 6th runs of the Muck game have been included even though there were only 5 and 2 attempts at these respectively. There was also a single instance of a seventh run of the game in year 3 for user KNJK7 which reached 56% progress in around 20 minutes of play making a small loss to this point. It seems likely the student was using this run of the game for the purposes of revision as their examination was taken a few days later and the user also ran their 5th and 6th runs of the Muck Game just prior to the 7th. It has not been included in table 9.11 due to space limitations.

Due to the small number of attempts beyond the 4th run of the game and the fact that 4 runs of the game is the standard allocation to students, analysis of the data will obviously concentrate on the first 4 attempts.

A chart showing the mean average and range of values for profit made in the Muck game for each of the four runs of the games is shown in figure 9.14. From this, the improvement in performance with repeated play is clearly visible. There is a huge change in the range of profit between runs 2 and 3. This shows in general that the first two runs of the game form the main learning curve for the Muck game and the final two runs represent the student's optimisation of their performance.

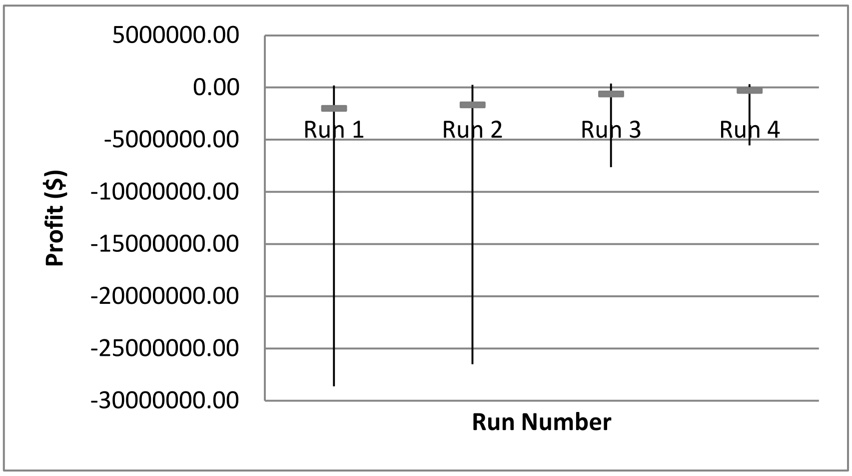


Figure.9.14 : Graph showing profit range for the four runs of the Muck Game

9.5.2 Canal Game

Key variables from the full set of data collected from the Canal game during the initial four years of running the ACPM are given in tables 9.12 and 9.13. Similarly to the analysis of the Muck game in section 9.5.1, a chart comparing profit against daily progress is shown in figure 9.15. This time the data is just split into those making a loss and those making a profit.

From table 9.12 a few points can be made:

- For those students who get past the initial 5% of the game completion rates are high.
- The amount of re-planning in the Canal game is quite low on average
- Profitability is lower for those reaching 5% than for those completing the game. This is probably due to the fact that the initial stage of the Canal project is the most costly part.
- Values for the summary measure are low for the Canal game showing that the student's find it easier to work to their plan in this game.

variable	Statistic	All players	>5% Progress completed	Completed games only
Number of Players	Started	235	159	122
	Finished	122	122	122
	%Finish	51.91	76.73	100
Time Spent	Mean	242.63	334.82	332.14
	SD.	301.28	323.41	231.14
	Min	0.08	21.43	21.43
	Max	3164.70	3164.70	1127.40
Project Duration	Mean	250.47	369.80	410.26
	SD	202.31	128.29	86.30
	Min	0	20	238
	Max	745	745	745
Project Spend	Mean	4,792,961	7,075,624	8,115,911
	SD	4,792,761	4,223,324	3,059,548
	Min	0	342,427	4,387,910
	Max	26,339,401	26,339,401	26,339,401
Number of Plans made	Mean	2	2.81	2.74
	SD	2.35	2.37	2.36
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	-351,721	-525,076	-315,632
	SD	3,007,241	3,643,118	4,059,729
	Min	-18,539,401	-18,539,401	-18,539,401
	Max	3,415,376	3,415,376	3,415,376
Daily Spend	Mean	13,127	18,498	19,392
	SD	10,353	6,365	6,655
	Min	0	9,393	12,078
	Max	56,018	56,018	56,018
Maximum Summary Measure	Mean	504	688	817
	SD	4,305	5,051	5,760
	Min	0	143	143
	Max	64,132	64,132	64,132
Final Summary Measure	Mean	49	64	52
	SD	64	65	48
	Min	0	3	3
	Max	564	564	304

Table 9.12 : Selected variable values for all players of Canal Game on ACPM Module

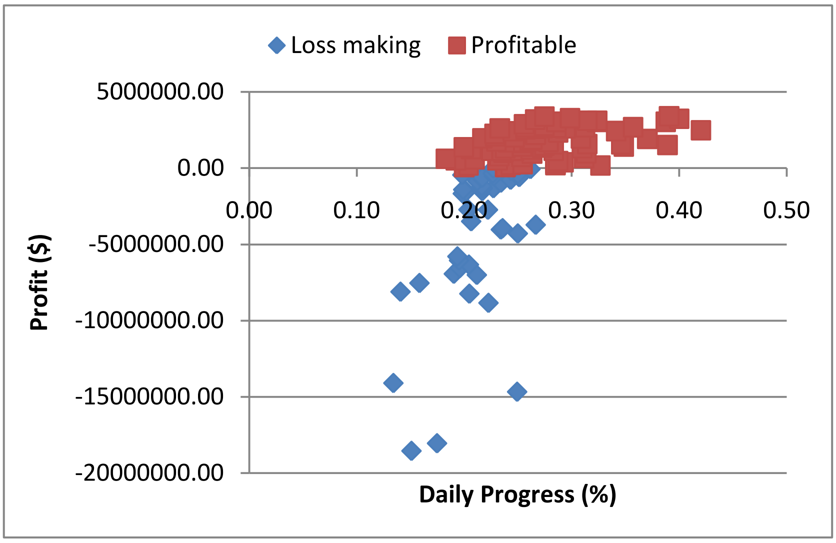


Figure 9.15 : Chart showing relationship between profit and rate of progress for the Canal Game

Daily progress rates are lower for the Canal game due to the differences between the two simulations. In this instance the link between profitability and progress rate is less clear with only those at the extremely low end of progress (less than 0.17) showing a loss in all instances.

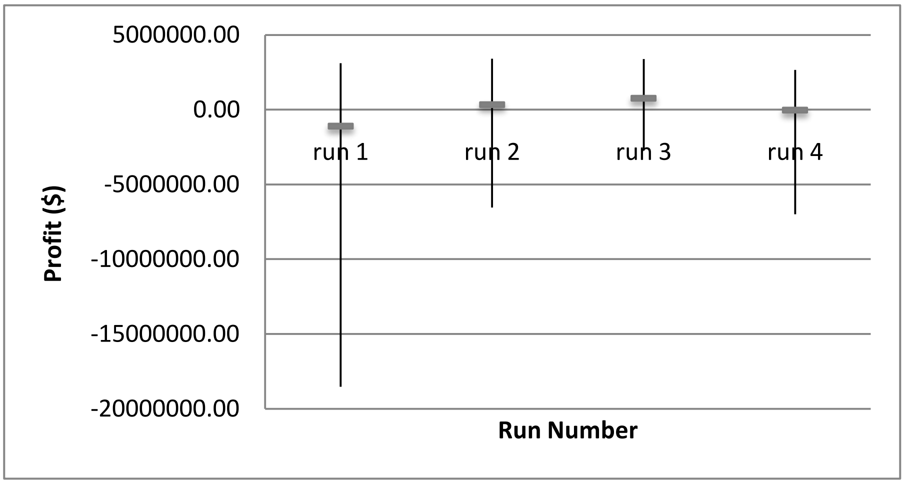


Figure 9.16 : Graph showing profit range and mean value for first four runs of the Canal Game

variable	Statistic	Run 1st	2nd	3rd	4th	5th
Number of Players	Started	120	62	37	13	3
	Finished	56	36	22	7	1
	%Finish	46.67	58.06	59.46	53.85	33.33
Time Spent	Mean	250.11	224.78	255.99	251.98	107.47
	SD.	246.92	221.59	240.30	346.31	140.50
	Min	0.13	0.12	0.08	0.10	0.75
	Max	3164.70	998.93	864.55	1127.40	305.98
Project Duration	Mean	248.02	259.16	257.59	238.92	131.00
	SD	208.78	197.63	190.89	188.72	185.26
	Min	0	0	0	0	0
	Max	745	547	520	472	393
Project Spend	Mean	5,264,004	4,469,116	4,108,322	4,463,643	2,508,770
	SD	5,617,771	3,764,844	3,258,657	4,242,632	3,547,937
	Min	0	0	0	0	0
	Max	26,339,401	14,341,134	10,525,676	14,796,509	7,526,310
Number of Plans made	Mean	2.28	1.76	1.65	1.85	0.67
	SD	2.70	1.84	1.98	1.87	0.94
	Min	0	0	0	0	0
	Max	10	10	9	6	2
Overall Profit	Mean	-1,102,843	345,217	766,936	-28,235	91,230
	SD	3,664,058	1,871,142	1,498,230	2,286,074	129,019
	Min	-1,853,401	-6,541,134	-2,725,676	-6,996,509	0
	Max	3,115,640	3,415,376	3,385,496	2,658,389	273,690
Daily Spend	Mean	14,198	12,462	11,006	14,011	6,384
	SD	11,418	9,459	7,634	9,282	9,028
	Min	0	0	0	0	0
	Max	56,018	48,040	23,390	31,349	19,151
Maximum Summary Measure	Mean	799	221	174	192	59
	SD	6,015	245	129	179	84
	Min	0	0	0	0	0
	Max	64,132	1,343	580	738	177
Final Summary Measure	Mean	61	42	29	42	2
	SD	73	55	31	66	3
	Min	0	0	0	0	0
	Max	564	304	154	238	7

Table 9.13 : Canal game statistics by run for all ACPM Data

Table 9.13 shows the variable data for the Canal grouped by run number and figure 9.16 shows the range of profits for the first four runs with the mean average indicated by the yellow circle. The third run of the Canal game clearly shows the best financial performance on average and the lowest divergence of values for profit. Reasons for the drop in performance in the 4th run are possibly due to:

- The small population size reaching this point skewing the results
- Some students who reach the 4th run have been unable to perform well up to this point (and through previous experience at the Muck game) indicating that they have failed to understand the nature of the simulations
- Other students who have already produced good performance at the Canal game use this run to experiment with the simulation (this behaviour has been observed in weekly clinic sessions and confirmed with students verbally)

9.6 Comparative analysis of Muck and Canal Performance

One of the objectives of this research (see objective 6, page 1) was to determine the extent to which students would be able to apply knowledge learnt in a simulation game. As stated in chapter 5, the Canal Game was developed to specifically help answer this question. The scenario in the Canal Game is very different to the Muck Game though the overall structure and working of the two games is very similar.

In this section, overall data collected during the ACPM module is analysed in order to examine the degree to which knowledge learnt in running one of the games can be seen to be applied in the other game. An assessment of this issue from the perspective of an individual student's data is provided in chapter 10 (see section 10.4).

Looking at the tables for all student data for both games (tables 9.10-9.13) it also appears that student performance at the Canal Game was significantly better than with the Muck Game. There are two main reasons to which this can be ascribed:

1. The project settings for the Canal game make it easier to complete within the timescale and financial constraints
2. Previous experience at playing the Muck game and the lessons learnt from it make completing the Canal game easier to achieve.

Previous experience at running both games in trials and in designing the module mean that point (1) can be confirmed and is in fact intentional (as referred to earlier in section 8.3.1.4). It is the extent to which point (2) can be verified which is of greatest interest in terms of the aims of this body of work.

The time spent idle, reviewing the assistance and making decisions indicates that the students had less difficulty in managing the canal project than with the dam project and that this cannot be entirely ascribed to be due to the differences in difficulty described. Therefore there is evidence that prior learning through the Muck Game can be usefully applied in the Canal Game. However, how much of this is learning the teaching material and how much is learning to play the game cannot be easily differentiated.

There are a number of obstacles in terms of comparing variables across the two games as many of the measures are dependent on the project scenario and are therefore not directly comparable. One variable however is directly comparable, the *SummaryMeasure.* As described in section 8.2, this value is a composite of a number of financial and progress measures and represents how well the simulated project is progressing to the current plan. High values represent a wide divergence from plan and therefore poor performance. The improvement in performance from the Muck to Canal games for this variable is clearly evident in the tables shown for each game (tables 9.10-9.13) but will also be illustrated graphically below due to its importance in assessing cross-game performance.

Figure 9.17 shows a radar chart displaying the mean averages of maximum and final summary measures for all students measured against run number. The extremely high values for maximum summary measure for the Muck Game make impossible to view the corresponding data for the Canal Game and figure 9.18 is shown to alleviate this problem by excluding the Muck game Max Measure. Figure 9.17 illustrates the improvement in student performance across subsequent runs of the game for all the values shown with the largest improvement from first to second runs.

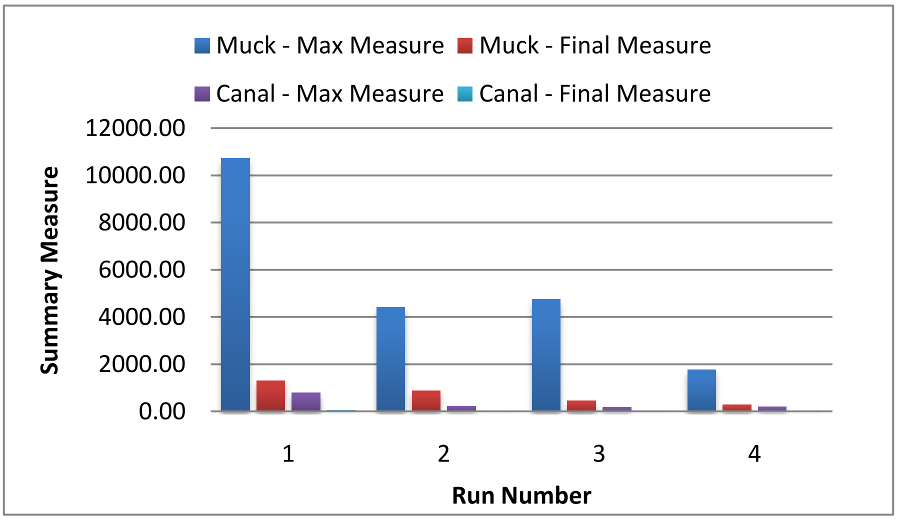


Figure 9.17 : Chart comparing performance at Muck and Canal Games through summary measure statistic

It is clearly evident from figures 9.17 and 9.18 that students are able to work to their plans much more easily in the Canal Game than in the Muck Game. Both the maximum and final summary measures for the Canal game are significantly lower than the final measure from the Muck Game. Since the vast majority of students complete the Muck Game before making significant progress at the Canal Game it seems that the experience of using the Muck Game is useful experience for running the Canal Game.

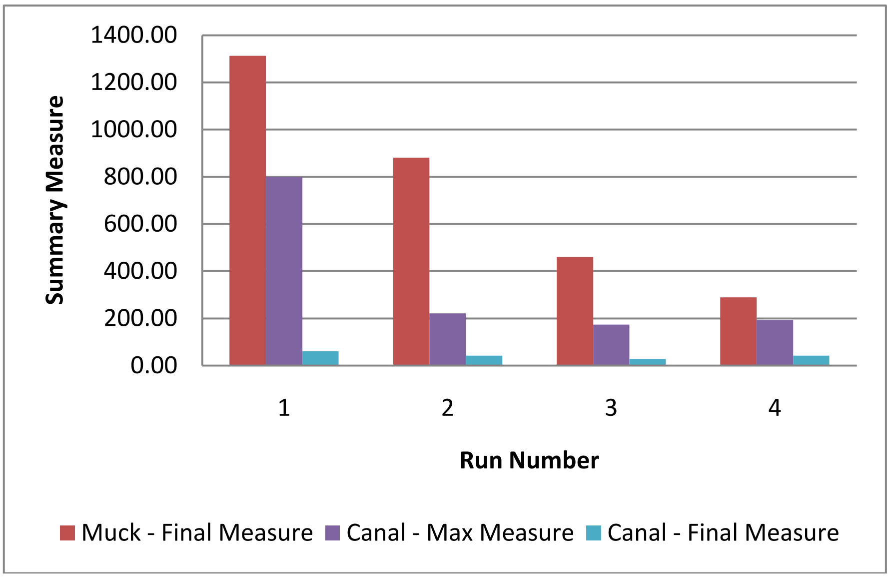


Figure 9.18 : Radar chart comparing performance at Muck and Canal Games via Summary Measure excluding maximum values for Muck Game

For the Canal game's average maximum measure, after a large increase in performance from run 1 to run 2 there is little improvement between 2nd 3rd and 4th run. The improved performance at the Canal game in comparison to the Muck game is most likely due to the fact that the students have already learnt the structure and user interface of the game through their experience with the Muck game.

Another major difference between the two games that may be partially responsible for any differences in performance is the temporal constraints of the two projects. This effect is particularly noticeable in years 3 and 4 when the difficulty of the Muck game was increased due to changes in climate and project start dates. In the Muck game, the students are under greater time pressure to complete the project within the specified constraints. This limits their ability to choose their rate of progress to suit the simulated conditions. In the Canal Game there is greater freedom from project deadlines, allowing the student to select a method of working that suits the simulated conditions. For example, they are able to shut down the site completely during the wettest period and avoid the expense of operating in poor conditions. It is much more difficult for the student to achieve this under the Muck game's temporal constraints and if they are to do this, they must heavily increase their productivity in the dryer condition with the significant costs and risks associated with high productivity.

9.7 Analysis of qualitative data

Data collected through in-game feedback forms was collated and analysed. All questions are answered by positioning a slider control to the level of response appropriate. Responses are annotated with examples for the extreme and mid-point values and the range of values possible goes from 0 to 10 with all sliders positioned at the mid-point value (5) by default. The questions asked in the form are shown in Table 9.14.

ID	Question	Response			Question Type
		Value 0	Value 5	Value 10	
Q1	Compare current progress to your ORIGINAL plan	Much Worse	To plan	Much better	Performance
Q2	How realistic do you think the simulation is?	Very unrealistic	OK	Very realistic	Game
Q3	Has the simulation highlighted any aspects missing from your ORIGINAL plan?	None	Some	Many	Performance
Q4	How useful is the simulation for gaining experience in management techniques?	Useless	Reasonable	Very useful	Game
Q5	Rate the amount of control available	Much less than real life	Similar to real life	Much more than real life	Game
Q6	Rate the reporting provided by the project	Much less than real life	Similar to real life	Much more than real life	Game
Q7	Compare current progress to your CURRENT plan	Much worse	To plan	Much better	Performance
Q8	Assess the time you have spent on the simulation (to this point)	Very little	Reasonable	Much too much	Performance

Table 9.14: In game feedback questions and set of responses available

As can be seen from the table, low value responses are negative and high values correspond to positive responses for the *game* type questions. For questions relating to *performance* the responses are more complex. For example, a low response in question three could indicate that the student had planned well or that the simulation was not effective. Equally a high response could show the effectiveness of the simulation or the inadequacy of initial planning. For questions 1, 7 and 8, a median answer represents optimum response and high and low responses represent the opposing ends of the spectrum in respect of those queries. Both high and low responses have negative connotations, though students are not always initially aware of this (especially with regard to questions 1 and 7).

Question type shows whether the question is aimed at analysing student's reflection on their in-game performance or requires them to give their assessment on the simulation game. Half the questions relate to performance and half to the game.

Figures 9.19 and 9.20 shows mean average results for each year of operation for the Muck and Canal games. Figures 9.21 and 9.22 exclude data where no change was made to the feedback form, all sliders left in neutral (value 5) position.

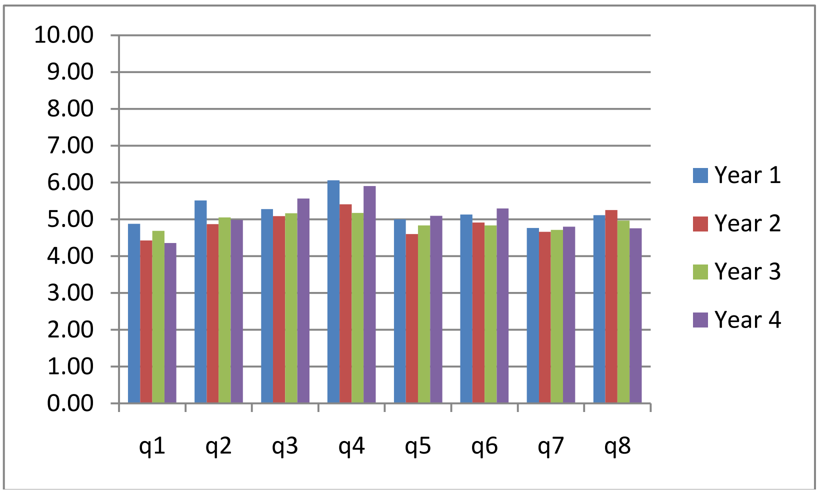


Figure 9.19 : Mean average responses values to in-game feed feedback questions for Muck Game (all responses)

The graphs including unchanged feedback data (figures 9.19 and 9.20) will not be discussed further since any trends or findings from this exercise are more clearly visible in the other graphs. In terms of overall response levels from this data collection, 1351 feedback forms were logged with 637 of these showing changes to the default neutral response. This response rate of 47% is high considering that each student is potentially required to complete the form 24 times (if they complete all four runs of both games) and are not forced (only politely asked in the introductory lecture) to complete the feedback forms.

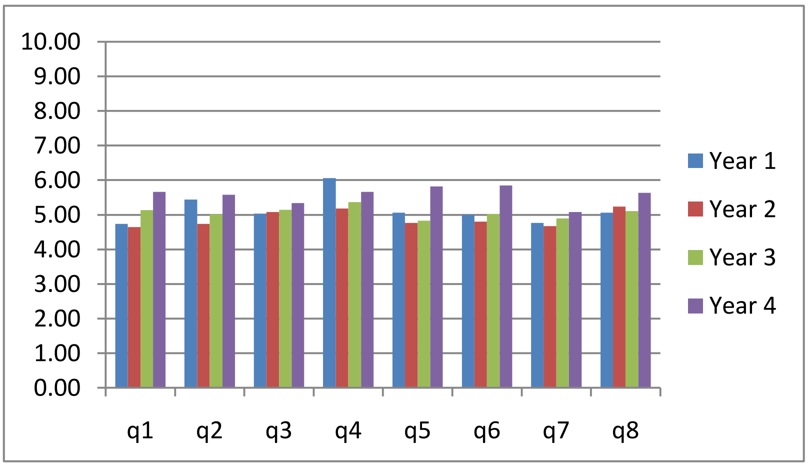


Figure 9.20 : Mean average in-game feedback responses for Canal Game (all logged data)

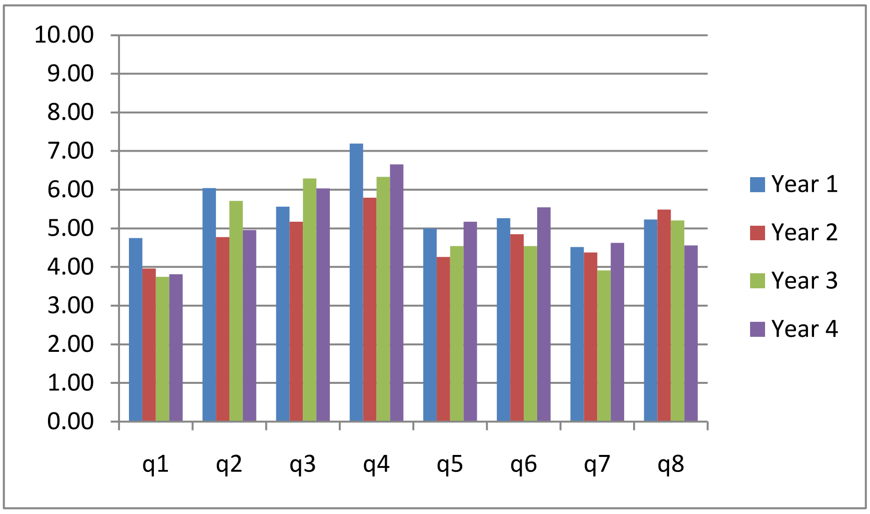


Figure 9.21 : Mean average responses values to in-game feed feedback questions for Muck Game(changed values only)

Figure 9.21 shows the results for the Muck Game with a line shown for each year of operating the module. It can be seen that each year follows a similar pattern of response to the questions in general though the magnitude of response varies for each year. Year one shows the most positive response overall with the highest responses for three of the eight questions (1, 2 and 4). Question 4, rating the usefulness of the simulation and gaming approach to teaching construction management, shows the most positive response overall. This is an encouraging response illustrating the higher than typical engagement of students with this method of teaching. Although, care must be taken in reading too much into this result since it may simply be a case of the student's telling the teaching staff what they believe the teaching staff want to hear.

Questions 1 and 7 show the lowest response levels indicating that the student's find it difficult to perform to their plans. The most negative response in terms of feedback on the Muck Game itself is for question 5. This shows that the students feel that they do not have enough control over the simulation. This is a common complaint for management type simulation games. Players inevitably would like complete control over events but their agency (see chapter 3) is intentionally limited to make a more realistic simulation of the realities of management. To increase player control over the simulation would increase their enjoyment and performance but would reduce the realism of the experience and therefore the learning opportunities that it affords.

Figure 9.22 shows the average responses for the in-game feedback received from the Canal Game. The overall pattern of response is very similar to that shown for the Muck Game in figure 9.21 and the points made previously remain true. However, the average responses are significantly higher for most questions and especially for year 1. It seems to indicate that the students were in general more positive about both the game and their performance at it. Their improved assessment of their performance is not surprising and to be expected given the differences between the games and the students' performance at each described in section 9.6.

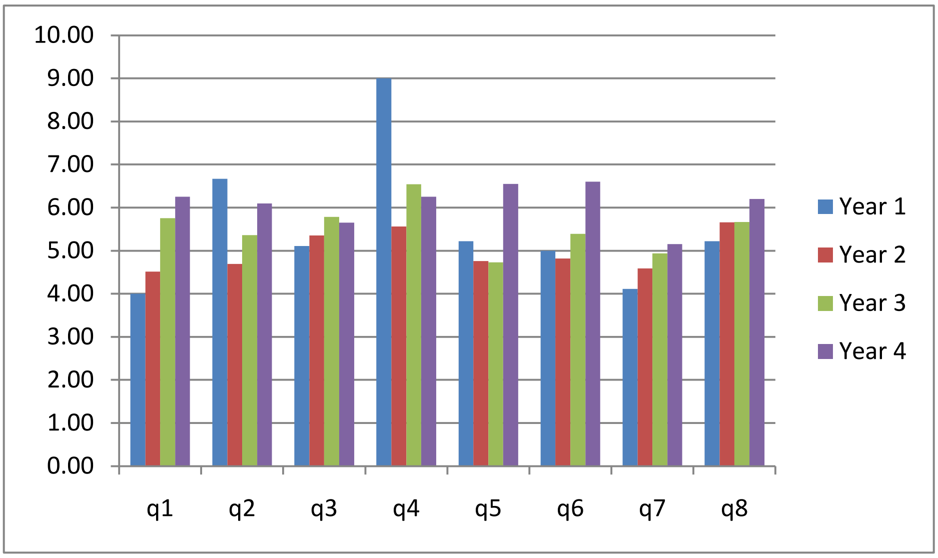


Figure 9.22 : Mean average in-game feedback responses for Canal Game (changed data only)

The improved feedback on the Canal Game over the Muck Game is more interesting since anecdotal evidence provided verbally by students in the clinic and revision classes seemed to indicate a preference for the Muck Game in general. Reasons for this difference could be due to the following:

- Previous experience playing the Muck Game (which is the experience of the majority of students) has enabled the student's to gain experience and practice in operating the games and their user interface. This has meant that their response to the games is not clouded by the learning curve. They are more familiar and forgiving of the game's structure, gameplay and interface.
- Positive responses to a game are partially determined by performance. Students are likely to have a more positive view of a game if they perform well at it.
- The difference in response levels may be partially due to the reduced size of the data obtained for the Canal game over the Muck game skewing the dataset (180 compared to 457 changed responses).

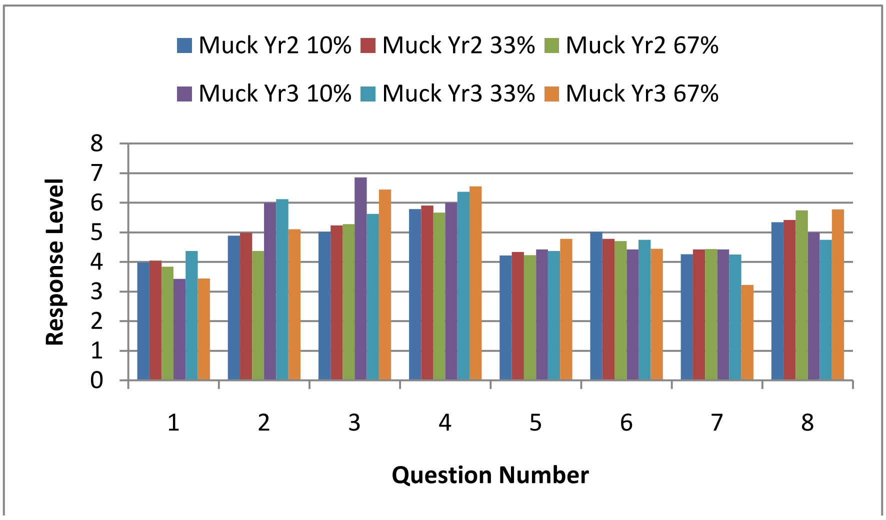


Figure 9.23 : Mean averages of feedback responses for Muck Game (changed data) classified by progress

It was decided to analyse the data by grouping it at the point of progress at which the feedback was triggered to examine if there was any relationship between student progress and feedback. Figure 9.23 shows the results of this analysis for the Muck Game (the larger dataset) for years 2 and 3 of operation. There are no statistically significant conclusions that can be drawn from this chart due to the small population of data but there are some interesting trends:

- Average responses from year 2 remain consistent across progress points with a slight fall at 67% for questions 1, 2, 4 and 6. Question 8 shows a marked rise in response at 67%
- Question 4 is the only question where the average values are positive in all instances in figure 9.22. This shows that students remain positive about the usefulness of this approach to teaching construction management throughout the simulation. For year 2, the average rises at 33% progress and then falls back at 67%. In year 3, the average rises with progression through the simulation.
- Question 1 shows the most negative responses indicating that students do not think their performance is going as well as their original plan. Interestingly, in both years shown in the graph there is an improvement in the average at 33% progress which then falls back again at 67% progress. It is likely that this is due to the onset of poor weather in the simulation (which will occur between these two points) causing the students' performance to fall short of their original plan by a greater margin
- For question 7 responses are similar, with some slight improvement, to question 1. This is as expected since this question compares their

performance to their current plan rather than their original plan. However, in year 3 then responses at 33 and 67% progress are actually lower on average than those for question 1 implying that any re-planning done has resulted in a plan worse than the original plan. It could also simply represent an anomaly in student responses which is not untypical in this type of qualitative data collection process.

- Question 2 shows a decline at 67% for both years shown in the bar chart which may indicate students becoming more aware of limitations in the simulation with greater familiarity. For year 3, the responses were initially positive and only declined to a neutral position unlike year 2 where responses started neutrally and became slightly negative.

9.8 Comments on the analysis of ACPM data

The data collected on student performance and activity during the ACPM module has been discussed and analysed. Improvement to student performance at the games on repeated play has been clearly demonstrated. A series of variable measures that assess student performance, and indirectly learning, have been identified and described. Key variables for the initial year of operation have been analysed in detail with discussion of what can be inferred from such data. Key variables from the other years of the ACPM module have been discussed with particular regard to differences found in each year and how it may relate to the various changes made to the ACPM module over that time.

The full set of data collected over four years of running the ACPM module has been collated and grouped in a number of categories to provide answers to many of the research aims and objectives outlined in chapters 1 and 3. This has been used to look at the transfer of learning between the two games and it has been shown that performance shows definite improvement when moving from the Muck game to the Canal game (the typical way of working for students) that cannot be easily discounted as being due solely to the differences in the scenarios.

There appears to be no simple relationship between game performance and module assessment marks. This is not that surprising and has been identified by others as an issue with blended learning methods (see chapter 3 for a full discussion of this issue). Other reasons more specific to the ACPM module have been provided such as the difficulties in mapping individual assessment data onto game performance data that is commonly generated in a group based fashion.

In-game feedback has been collated and used to gain an impression of student's opinions on the ACPM module, the games used and their own performance.

The response level was high considering its voluntary nature and the amount of feedback requested. A strong positive response from students regarding the usefulness and engagement of learning construction management through simulation games was recorded. This backs up anecdotal evidence found during the teaching process. The Canal game receives a more positive response from students, both in terms of the game and their performance at it even though it is played much less than the Muck game.

10. ACPM Module – Analysis of individual student performance, behaviour and relationships to learning

This chapter continues the work analysing data gathered from the ACPM module described in chapter 9. However, in this chapter data is investigated at the individual student level rather than focusing on statistical measures for specified groupings of students. Analysis of individual student behaviour, performance and learning are detailed in depth using individual students chosen to illustrate specific findings or typical behaviours.

This section aims to demonstrate typical, exceptional, poor and anomalous examples of in-game behaviour. It aims to help answer the primary aim of the research and the sub-objectives posed in section 1.2 (specifically objectives 2, 3 and 6). Assessed elements of the teaching module are used to compare against in-game performance. Qualitative data collected is integrated with quantitative data in order to help ascertain the learning process occurring during the exercise.

In comparison to the high level data analysis carried out in chapter 9, the focus on individual students enables the analysis of performance throughout each run rather than the final state of variables. More detailed analysis is possible at this level of inspection and activity graphs are provided to show student activity throughout gameplay. Examples of performance across the two simulation games can be clearly shown at this level of analysis which assists in testing the hypothesis that learning in one game can be applied to a similar yet different exercise.

It is not practical to examine more than a small sample of the students who have taken the ACPM module, Students were chosen for inclusion in this chapter based on their relevance to the specific topics being analysed, as representatives of a general trend within the dataset or due to the richness of their individual data.

It is important to note that there are a range of constraints and limitations on any inferences or deductions drawn from an individual case. Specific details and examples of such issues are given in the following section (10.1).

10.1 Issues relating to the analysis of individual student data

It is crucial to consider a number of issues regarding the analysis of individual student data. The unsupervised nature of the gameplay that generates the data means that we cannot be certain that the student worked alone or with others. Idle time spent logged into the simulation games but not performing an activity may indicate thinking time or reflection by the student or it may simply indicate that were performing other activities. In examining a student's behaviour care must be taken to not draw conclusions based on a single, possible erroneous, activity.

It is difficult to assess a student's intent in playing the games unless articulated through the in-game messaging system. It is assumed that students are attempting to complete the simulation within the specified constraints but there are instances where their behaviour indicates a process of experimentation with the sensitivity of the simulation to specific inputs and overall performance may be misleading. Where identified, examples of this behaviour are given in this chapter.

10.2 Analysis of learning styles

As discussed in chapter 2, research has identified various cognitive mechanisms used by learners that relate to their individual aptitudes and the type of learning experience undertaken. The *learning styles inventory* used in Kolb's theory of experiential learning is of relevance here and analysis of data collected through the MCG Umpire can be used to identify specific learning styles adopted by students on the ACPM module. A full analysis of the learning styles of individual students using the Myers-Briggs method was not possible in this instance but specific instances of learning styles were identified during the research and are described in the following sections. These are illustrated using example case studies of individual student behaviour.

10.2.1 Learning by doing/trial and error

Students who appear to learn this way also appear to spend little time planning and reviewing the assistance materials provided. They make a rough draft plan based on the game instructions and run the simulation to examine the accuracy of the plan. They update the plan based on feedback from the game and will contact the teaching staff, their peers and/or review the assistance materials when they encounter difficulties in understanding what is happening with their simulated project. This is the most common behaviour exhibited by students on the ACPM module. It is illustrated below.

This example of trial and error gameplay looks at the performance solely at the Muck Game for student #1 (Muck usernames = FLNV1-4). This user completed all four runs of the game in numeric order and showed a higher than average performance at the game. Time spent playing the game on all attempts was lower than the average for other games in this year as shown in figure 10.1.

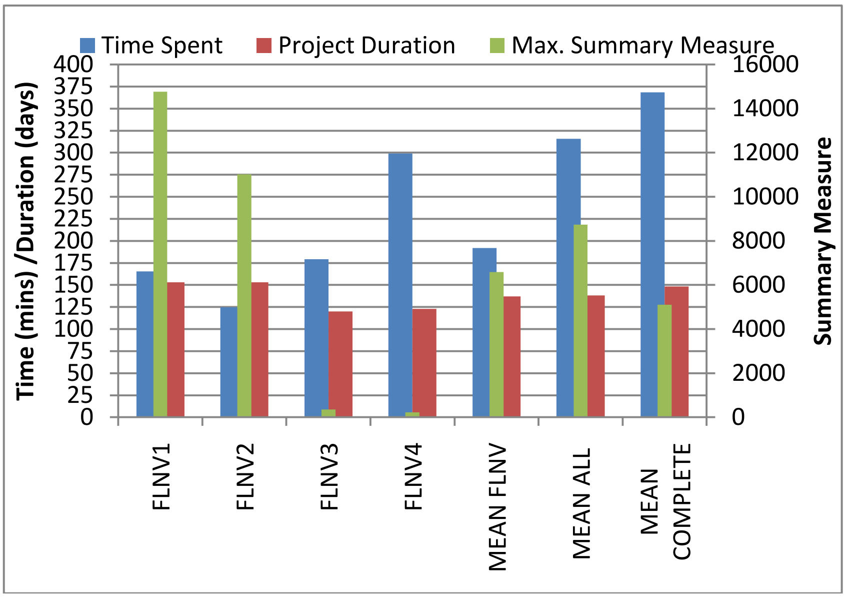


Figure 10.1 : Time spent, project duration and max summary measure for student #1 compared to average results for year 1

The chart also shows the project durations for all 4 runs and the maximum summary measure (high values represent overall poor performance to plan). The mean values for all four runs are also shown as are the mean values for all students and those completing the game in that year.

Student #1's maximum summary measure for attempts 1-2 was significantly higher than average (for themselves, all students and completed students) indicating that they had difficulty in performing to plan in the initial attempts. Attempts 3-4 show a significant improvement and coincide with greater time spent on the simulation. Figure 10.2 confirms the high relative financial performance for student #1 showing planned spend, actual spend and profit for all runs alongside averages for all and completed runs in that year. It can be seen that even student #1's worst performance in their initial attempt is significantly better than the average for all runs and only completed runs.

Typically, this represents a student who spends time on the first run understanding the process (though significantly less than the average for all and completed students) but not performing well. On the second run when they think they know what they are doing they spend less time and still perform badly. They then realise that project control is complex and requires additional time and attention. This is reflected in the time and performance in runs 3 and 4.

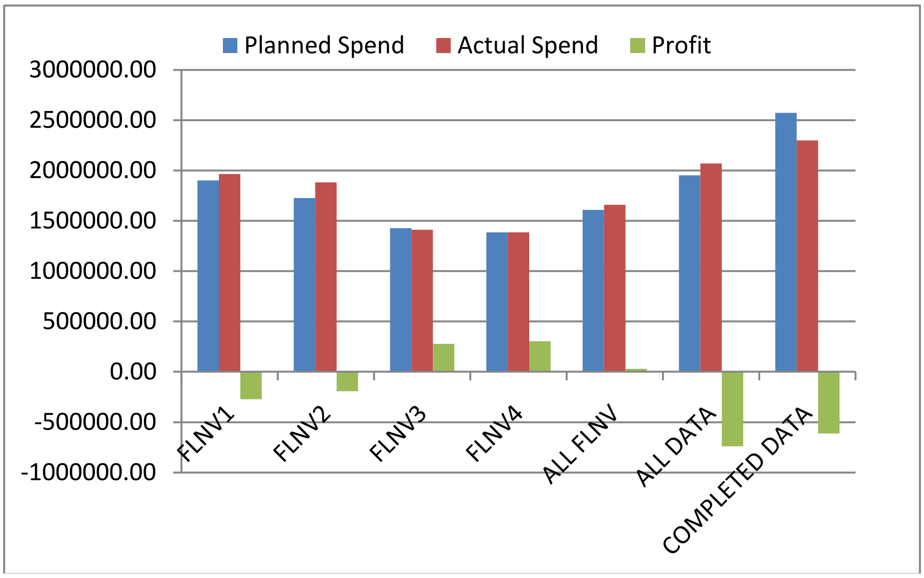


Figure 10.2 : Financial information for student #1 and comparison with average for all runs and completed runs

10.2.2 Extensive pre-planning

A number of students will analysis the game instructions in greater depth and download and study the additional teaching materials that are available to them before commencing their initial run of the game(s). They will often produce estimates of planned productivity for the project and use this to develop a *realistic* plan for the project. Commonly these students will find discrepancies between their calculated figures and the simulated results and will query these differences. An important teaching lesson is gained here in the explanation of the limitations of calculating accurate figures and potential variances in data provided to the project manager. For example, students often fail to realise that the productivity figures for plant equipment that they have been given are manufacturer's figures. They are likely to represent the best performance for the equipment in ideal conditions rather than the actual conditions that may occur on site.

This learning model is illustrated in figure 10.3, where student #2 spends a considerable amount of time on runs 1 and 2 learning the structure of the game and identifying the key parameters involved in planning and controlling the project respectively. This enables performance to improve in runs 3 and 4 whilst the time spent on the simulation actually reduces. The improved performance in later runs is confirmed by the graph of financial results shown in figure 10.4.

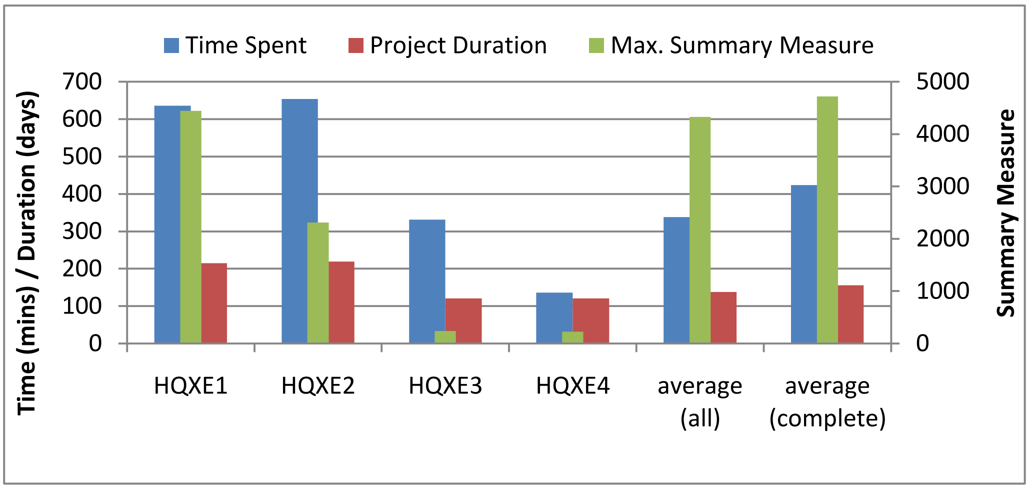


Figure 10.3 : graph for student #2 showing time reduction and improvement in later runs of the Muck game in comparison to average for that year of operation

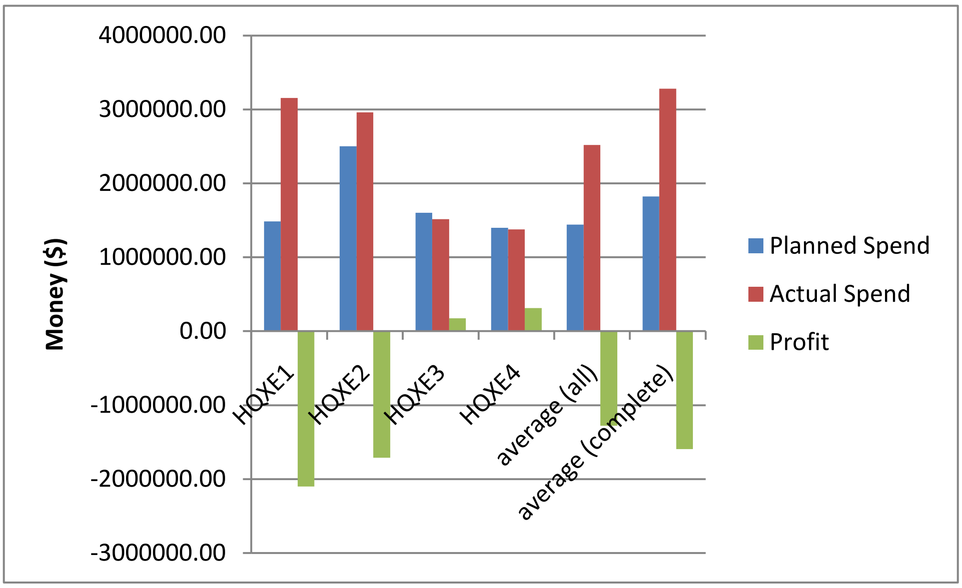


Figure 10.4 : Chart showing financial measures for student #2 and comparison to average for year 2 dataset

It is difficult to show extensive pre-planning performed outside of the simulation games though anecdotal evidence from the weekly clinics clearly identified students who spent considerable time planning and discussing the simulation with teaching staff prior to commencing the simulation.

10.2.3 Experimentation and Sensitivity analysis

This strategy is found in later runs of the games where the student has learnt the basic concepts of the project scenario and management issues. In order to improve their performance the student will attempt to analyse the sensitivity of the simulation to changes in specific parameters such as the type and number of specific resources or training budgets. Comparison of runs using the MCG Umpire can easily identify this type of behaviour and its effect on student strategy in subsequent runs.

A simple example of this behaviour is illustrated through analysing the behaviour of student #3 from year 4. This student completed the Muck Game successfully on their initial attempt at a performance level higher than their peer group. On their second attempt it was identified that they made numerous alterations to the haul road gradients throughout the simulation. This behaviour was not repeated in their third attempt and seems to indicate experimentation with modifying haul road gradients as a method for optimising performance which was then discounted in subsequent attempts. Figure 10.5 illustrates this behaviour showing profit for the three runs of the game and the changes to haul road gradients trialled in run 2. Statistics shown are compared against the average for that year. Their relatively high performance tends to indicate that the changes to gradients are not simply a desperate attempt to improve but more likely a conscious strategy. The fact that it is not repeated in run 3 though performance continues to improve could indicate that student #3 has determined that the changes to haul road gradients are not an effective way to improve performance.

In fact 20 runs showing gradient changes of five of more (in either field) and student #3 is one of only two showing a profit and the remaining 18 include some of the worst performers in the whole Dataset from all four years. The use of this type of experimentation as a desperate act indicating difficulty is described in section 10.6

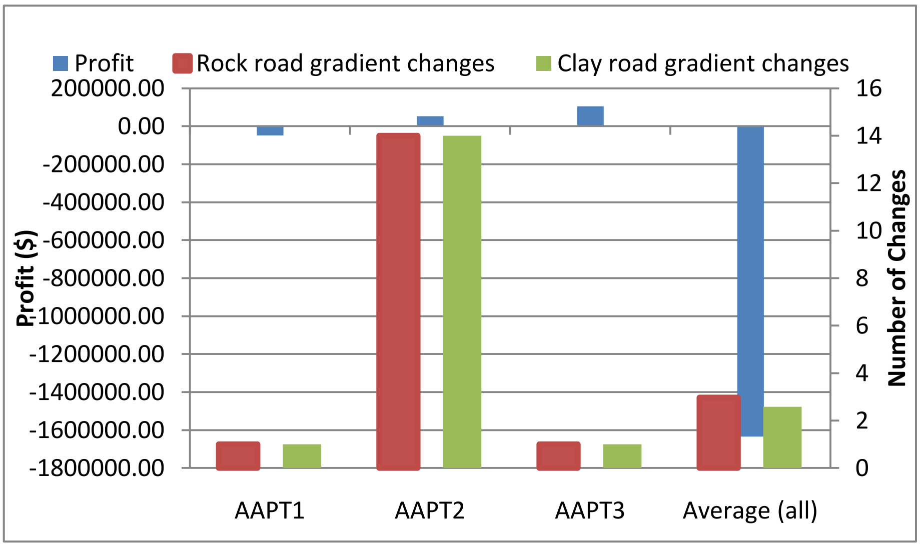


Figure 10.5 : Graph showing student #3 performance (in terms of profit) and their experimentation with gradient changes in run 2

Other examples of experimentation discovered by teaching staff during the weekly clinic sessions include the use of overtime options for resources and changes to the number of wet weather graders and thresholds for their employment. Both these options are generally employed in an attempt to further optimise project performance once a student has been able to understand the effects of standard resources and their allocation in both the Muck and Canal Games.

10.2.4 Learning styles and project planning

Students basically split into two groups with respect to their initial approach to project planning.

The first group consider the overall targets (they have to build 30m of dam in 40 weeks or 7km of canal in 100 weeks) and adopt a linear plan to achieve this. They take little account of detail and relatively little account of finance except in so far as they might attempt to 'guess' a reasonable profit and plan to make it. This type of approach is illustrated in figure 10.6. Although not shown in any of the graphs (because of lack of data in earlier years, see section 8.7.2) there is some evidence to suggest that this approach is more frequently adapted by students who learn by doing as described in section 10.2.1.

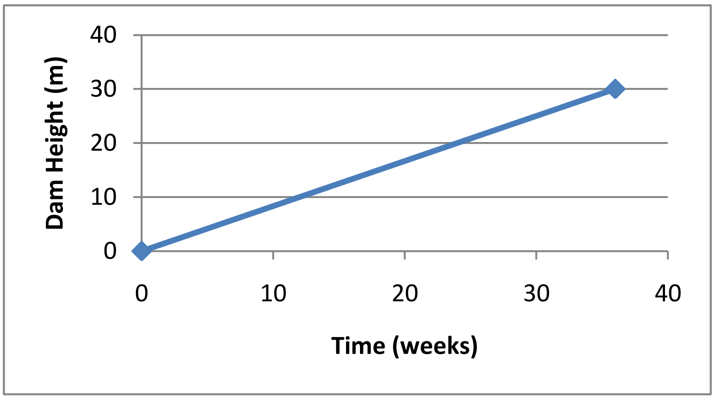


Figure 10.6 : A 'simple' linear plan adopted by student #3 in their initial run of the Muck Game

The second group analyse the project, usually in very great detail, and attempt to produce a very detailed plan taking into account all parameters which they are aware of. Such plans tend to have too much detail and are based on figures that, whilst provided by the game assistance material, are theoretically correct but ignore many of the practical aspects which affect the actual values. The plans are therefore often unachievable. A plan of this type is shown in figure 10.7.

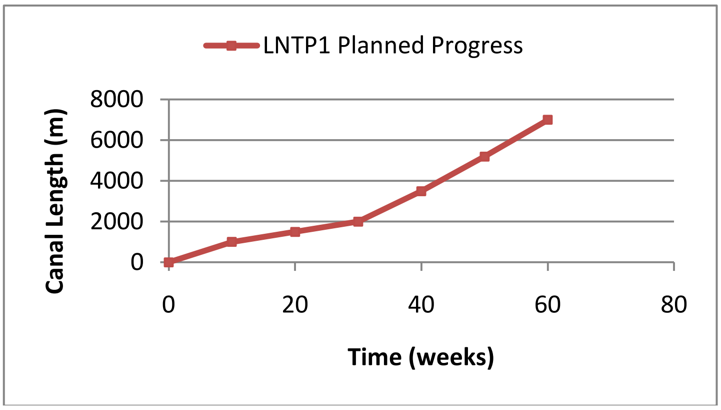


Figure 10.7 : A highly detailed plan adopted by student #4 in their initial attempt at the Canal game

Both of these groups learn the problems inherent in their approaches and converge on a more realistic planning style in which they identify the key drivers and plan to an attainable level of detail taking them into account. A typical plan produced this way is shown in figure 10.8.

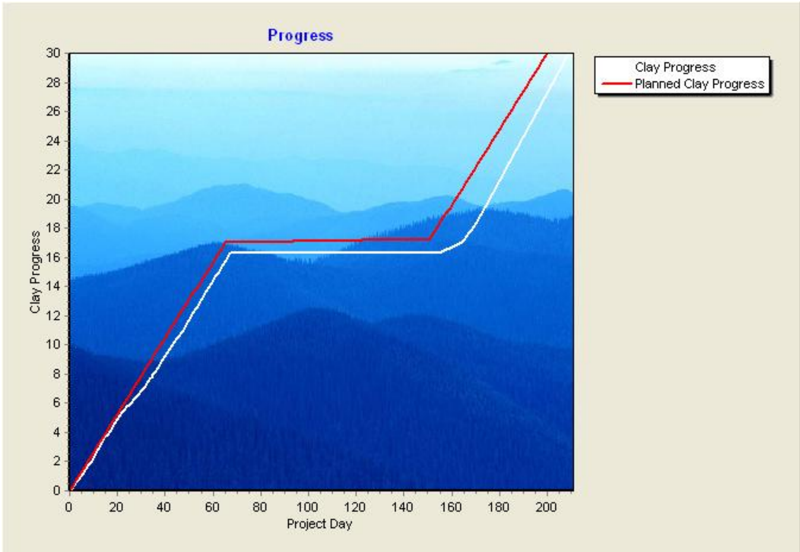


Figure 10.8 : Planned and actual progress for student #5

This figure also illustrates that such a plan is realistic and can be controlled to. The white line on the graph shows the student's actual progress. It can be seen that this follows the planned progress very closely.

10.2.5 General Activity

The different learning styles also become obvious when the activities of the students are analysed. Typical graphs illustrating this are shown in figures 10.9 and 10.10.

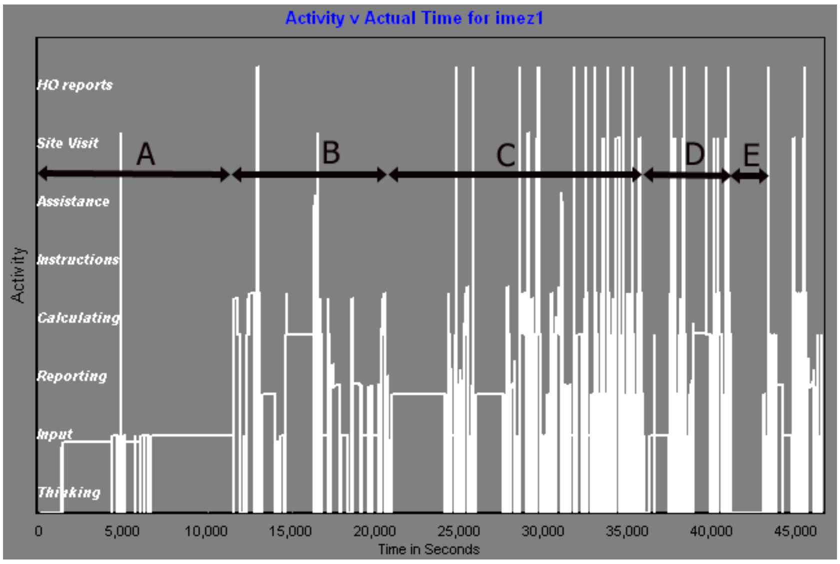


Figure 10.9 : Chart of student activity over time for student #6 run 1

Figure 10.9 is for a student who analyses the information before actually running the simulation. It shows student activity against actual time for run 1. A large amount of initial time is spent inputting the student's data and examining the project (section *a*). Activity in section *b* involves frequent operation interspersed with reporting and changes to student decisions. The student is gaining understanding of the project and game during this period. Section *c* indicates a period where the student is micromanaging the project and making steady progress. At point *d,* the student encounters heavy rain conditions and is forced to make changes to their resources in order to get the project back under control. Section *e* shows a time period where the student is using the game but is not in a particular section. It is likely that the student was consulting with teaching staff or his peers to decide his best options in light of problems. This is evident when additional data on the run is examined.

Figure 10.10 is for a student who does not spend so long on the initial analysis. It can be seen that first calculation activity is much earlier in the project than in figure 10.9 indicating a relatively rapid input phase.

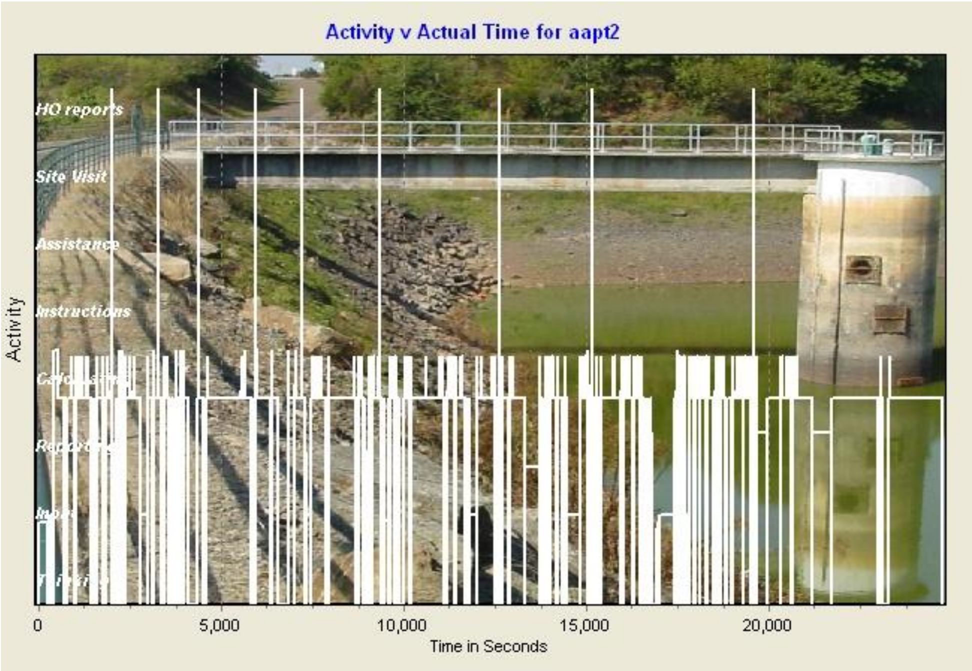
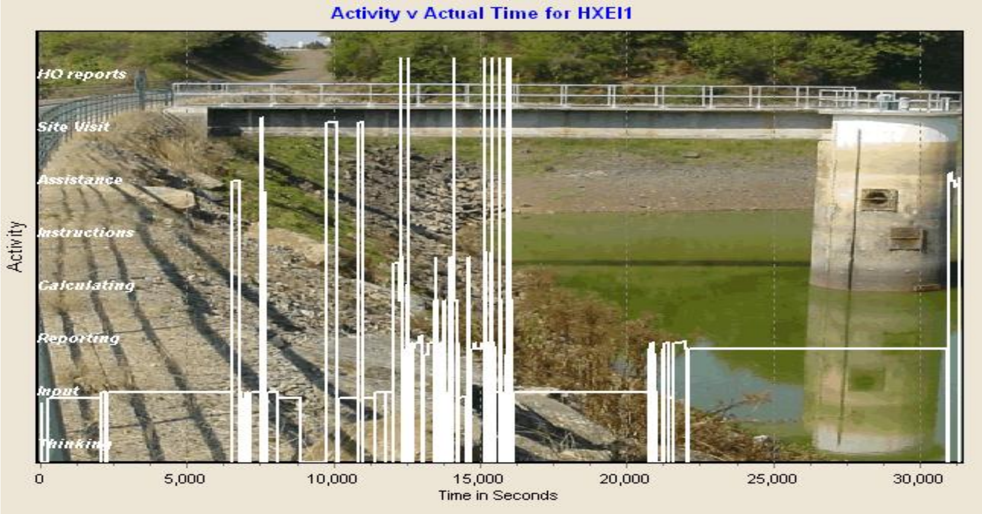
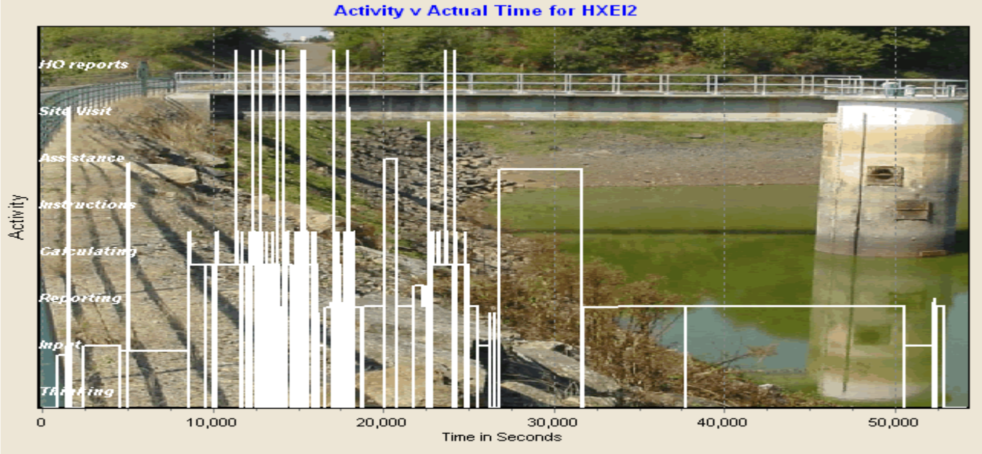


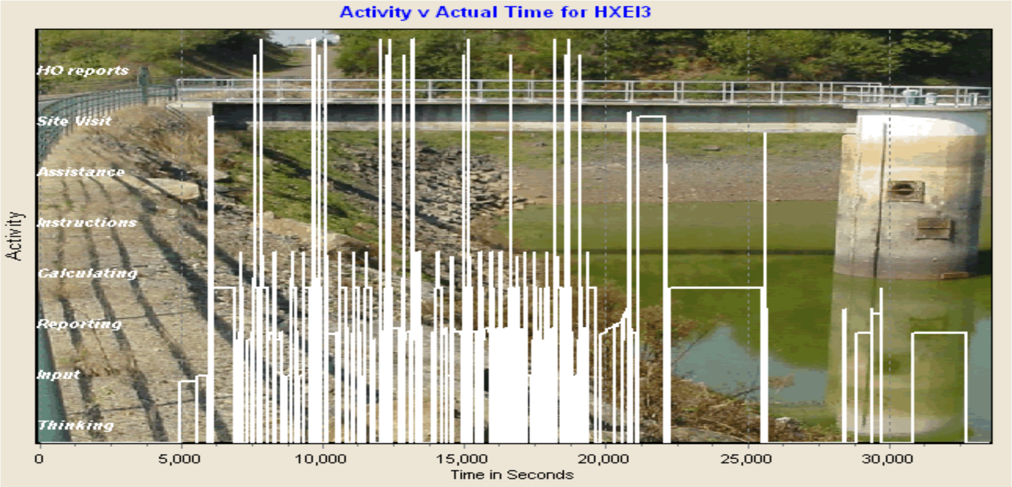
Figure 10.10 : Activity chart for student #3 run 2

Changes to student activity on repeated runs of the games are an important source of information on student behaviour and can be used to demonstrate that learning is occurring. Figure 10.11 shows activity graphs for all 4 runs of the Muck game for student #7.

An initial point to note when looking at the activity graphs for student #7 is the elapsed time spent. The first three runs of the game account for 30,000, 50,000 and 30,000 seconds of activity respectively whilst by the 4th run the student spends just 6,000 seconds completing the Muck game. In the later runs of the game and especially in run 4 there is significant clustering of activity by the student will little to no time delay between the calculating activities. It appears to be less clustered than sections of the other runs but this is due to the different timescales shown.


Activity v Actual Time for HXEI1
HO reports
Site Visit
Assistance
Instructions
Calculating
Reporting
Input
Thinking
Activity
0
5,000
10,000
15,000
20,000
25,000
30,000
Time in Seconds


Activity v Actual Time for HXEI2
HO reports
Site Visit
Assistance
Instructions
Calculating
Reporting
Input
Thinking
Activity
0
10,000
20,000
30,000
40,000
50,000
Time in Seconds


Activity v Actual Time for HXEI3
HO reports
Site Visit
Assistance
Instructions
Calculating
Reporting
Input
Thinking
Activity
0
5,000
10,000
15,000
20,000
25,000
30,000
Time in Seconds

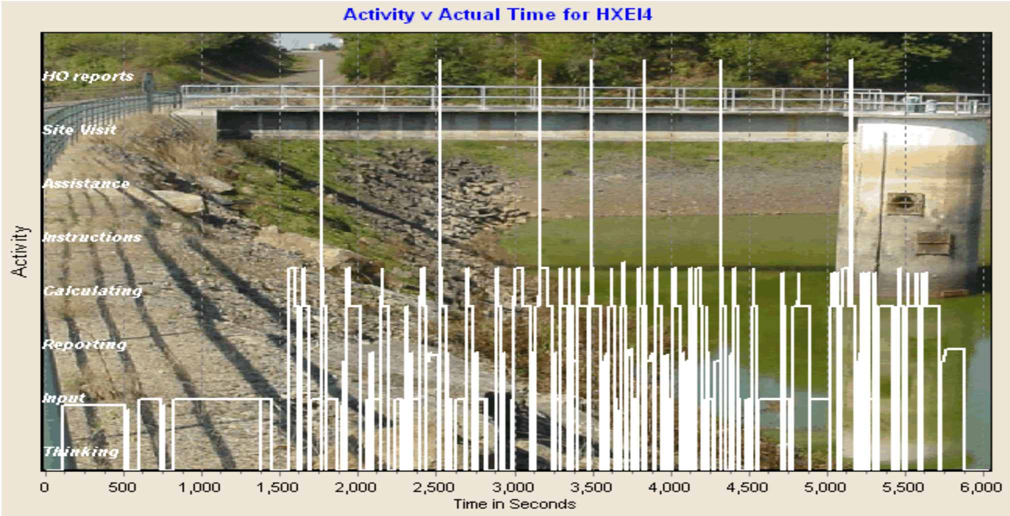


Figure 10.11 : Activity graphs for all 4 runs of the Muck Game for student #7

In run 1 there are long delays between activities and the student spends a significant amount of time inputting data to the simulation. They also make access the *site visit* element of the game a number of times. The student stops advancing the simulation at around 15,000 seconds but spends a great deal of time looking at reports and assistance materials for the remaining 15,000 seconds.

By the 3rd and 4th runs they no longer need to access the site visit element of the simulation (which contains information on the project site and climate conditions). They also spend considerably less time looking at reports with only short regular views of the head office reports to check their progress. In the 4th run there is a long period of thinking time or inactivity at the start of the simulation.

Overall a trend of changing activity can be seen over the 4 runs of the game very typical of student's activity graphs. Indeed student #7 was chosen as it illustrated this change in activity well.

10.3 Student reflection

The importance of reflection during the learning experience was identified in the review of the learning process in chapter 2 and the problems associated with establishing reflection when using simulations and games were discussed in chapter 3. Within the ACPM module reflection is encouraged informally during the weekly clinic sessions and via the use of in-game feedback and messaging systems. Data gathered through the latter methods is analysed in this section to show evidence of student reflection on the learning process. No attempt has been made to quantify the informal reflection which happens throughout the teaching module although discussions in the weekly clinic sessions indicate that considerable reflection occurs for some students and little for others,

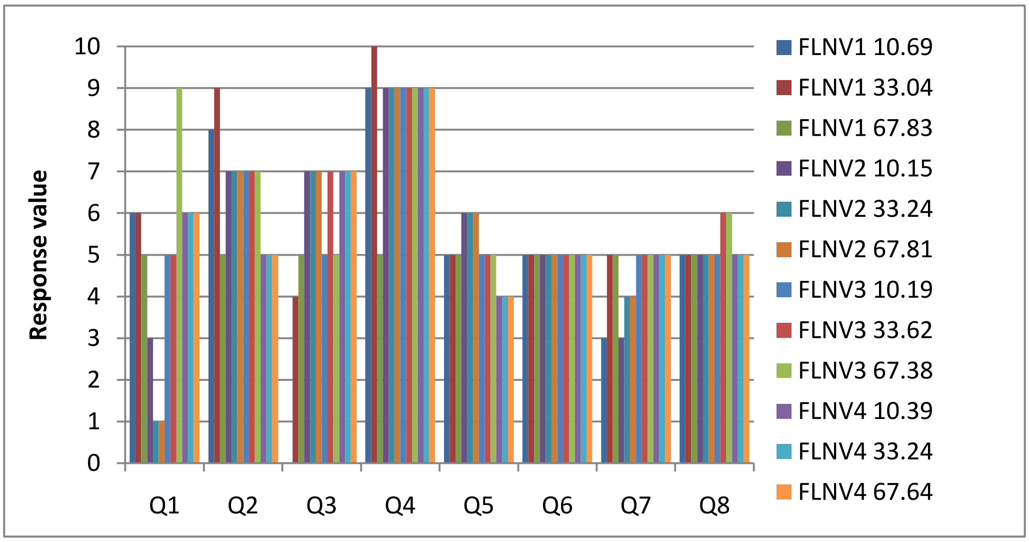


Figure 10.12 : Student #1 responses to in game questionnaire

Student #1 sent a total of 3 messages to the game umpire as shown in table 10.1. The issues raised were discussed with the student in clinic sessions and he was satisfied with the answers provided (even if he did not necessarily agree with all of them). Student 1 also completed the in-game questionnaire as requested and the results for each question number are shown in figure 10.12 (questions asked were given in table 9.15)

It can be seen from this that the student's perception was that the game was realistic and useful (questions, 2, 3 and 4). The student also judged that his/her performance on the project was not as good as it might have been at some points (e.g. question 1 for FLNV2 33.24%, FLNV2 67.81%). Both these indicate that the whole process of playing the game has encouraged reflection, both in terms of their performance and in how the game simulates the construction process).

Messages to the game umpire received from student #1 (shown in table 10.1) clearly show that student #1 has been reflecting on their experience in playing the Muck Game. Their final comment shows that they have been reflecting on the actual gameplay itself and devised an alternative method to resolve the issue they raise in comment 2. However, the nature of the reflection is concentrated on the simulated environment rather than actual construction management which may demonstrate a tendency to learn to play the game rather than to achieve the learning outcomes.

User	Date	Comment
FLNV1	09/02/06 10:38	My overall performance is apparently very poor, though my summary scores have been well below 80. Admittedly an engineer was fatally wounded last week, but safety expenditure has been increased and the funeral costs were covered by insurance. A week of work was lost, but the project should still finish on time.
FLNV3	11/03/06 11:47	The computer seems to have evolved artificial intelligence. I am trying to print out the results from my last project to get details for my CW, but the computer seems to be lazy and doesn't want to print any more, saying that it isn't 'superhuman'. If it is just human I feel like calling it into my office and telling it not to be so cheeky! And I want the reports on my desk by Monday morning. I think that this level of realism during the simulation would be good as the number of reports depends on the number of secretaries etc that are employed. But after the simulation has finished it is a bit annoying now as time is running out and I need to take information away to discuss.
FLNV4	23/03/2006 09:45	I think that a facility on the simulation that could allow the user to specify what information they wanted recording during the project would be beneficial. This could have a cost attached to it and could be subject to the program understanding what the user wants - the user must demonstrate clear and precise communication. I think that being able to ask for reports at any time during the project would be useful, but obviously the user would only receive the information for the duration after it was requested. This would show the cost-time benefit of making your own records or paying to have them made for you.

Table 10.1 : Messages to Umpire received from student #1

Figure 10.13 shows the feedback figures from a very different student (student #8). This student is generally positive about his/her own performance but negative about the simulation game (Q2, Q4-6). Detailed analysis of this student has shown that he/she performed well in the assessment (coursework and exams) but his/her performance at the Muck Game was quite variable (figure 10.14). Some scores for their own performance (Q1, Q7) start low and improve with repeated play which indicates improvement but is not fully backed up by analysis of the in-game data as shown in figure 10.14. The second run shows a decline in performance from their first run and is the worst attempt made. However, the drop in performance does occur late in the project which is reflected by their responses in figure 10.13 and shows that the student has reflected well on their performance.

The student made no progress at the Canal Game and their answer to Q8 indicates a belief that too much time has been spent playing the Muck Game which all adds to the evidence that student #8 did not enjoy this type of learning. This illustrates that the game style of learning does not suit all students.

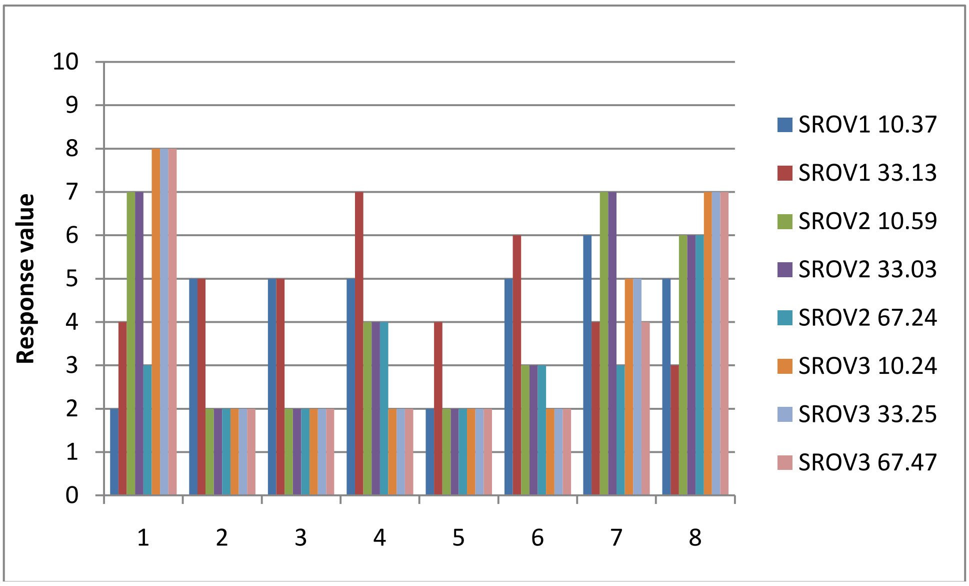


Figure 10.13 : In-game feedback results for student #8

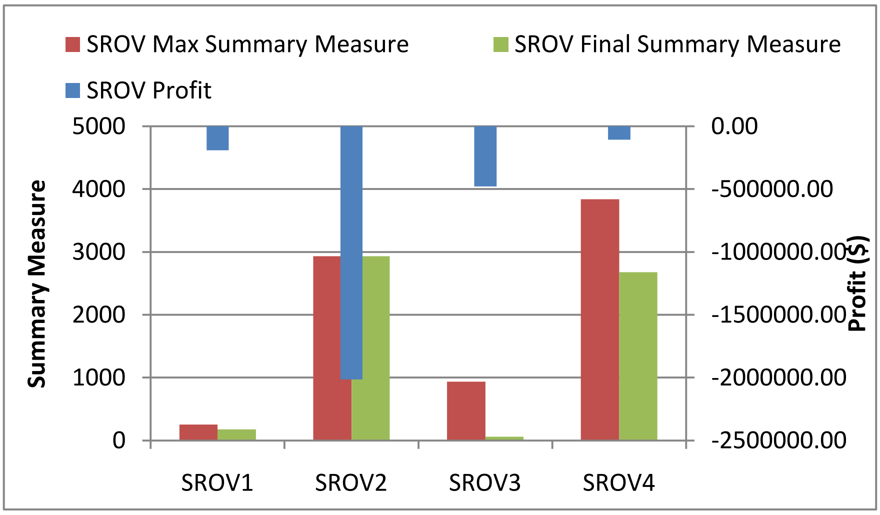


Figure 10.14 : Indicators of game performance for student #8

10.4 Application of learning across games

As stated in chapters 4 and 5, the primary motivation for the development of the Canal Game as a variant of the Muck Game was to allow for the investigation of transferability of learning and the application of knowledge learnt in a similar yet different simulated project. Some evidence of this was given in chapter 9 based on analysis of the full dataset of all students undertaking the ACPM module.

Student #5 (Muck username = BBPW, Canal username=IFYU) provides an example of a student who played all 4 runs of both games completing 2 of the Muck Games and 3 of the Canal Games.

As can be seen from figure 10.15, student #5 played through the runs of the games in numeric order and completed 3 runs of the muck game before starting the canal game. This represents typical behaviour though many students appear to start a run of the Canal game close to the time they commence the initial run of the Muck game. In actuality, investigation of the data files shows a tendency to log into the Canal Game to check that their username works but no other progress until some runs of the Muck Game have been completed.

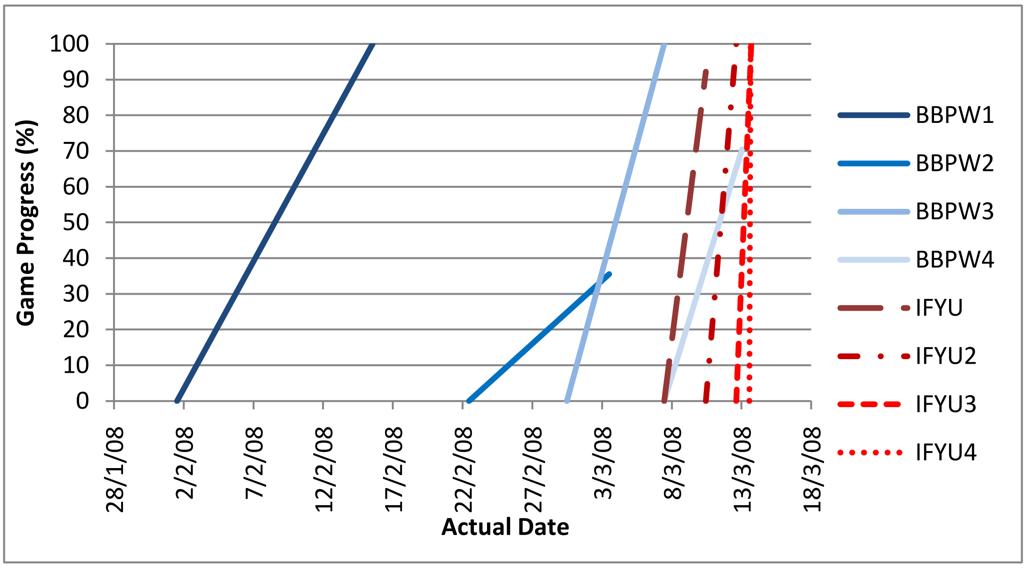


Figure 10.15 : Timeline chart showing progress and dates of play for example student #5

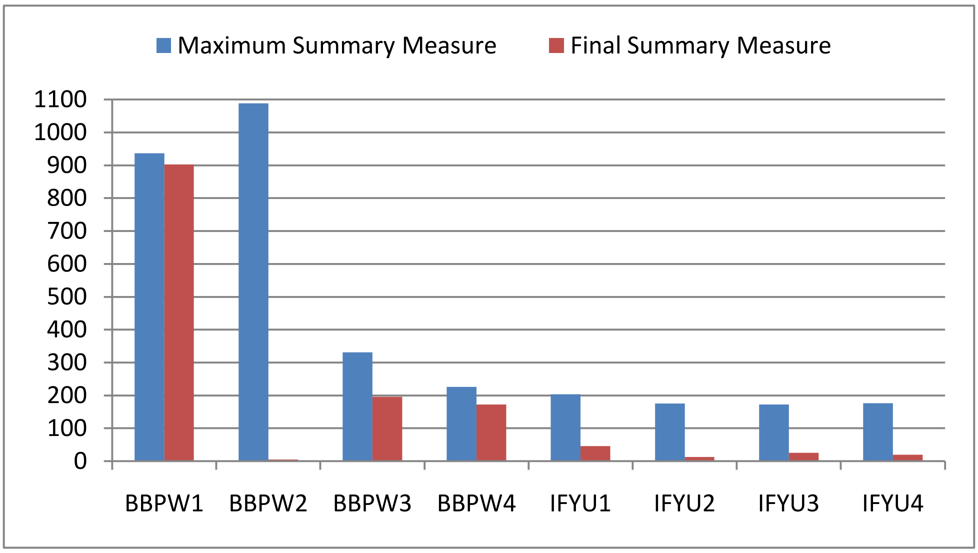


Figure 10.16 : Improvement in performance between Muck and Canal games for student #5

Figure 10.16 illustrates the learning on projects and learning transfer between projects. The projects are plotted in the sequence that they were started in (as shown in figure 10.15). The summary measure is used as a measure of performance because it is project independent (as discussed in chapter 9). Other measures such as 'profit' or 'project duration' cannot be used as they differ greatly between projects.

Similar patterns of performance are shown in figures 10.17 and 10.18 which are for a second student. This student is presented because the runs of the games were not clearly sequential but learning can still be seen to be happening between the runs. The student did make any changes to the in-game feedback form for any of the runs of either game. In terms of their assessed performance at the module they were 6th out of 65 for the module in their year (academic year 2006/2007)

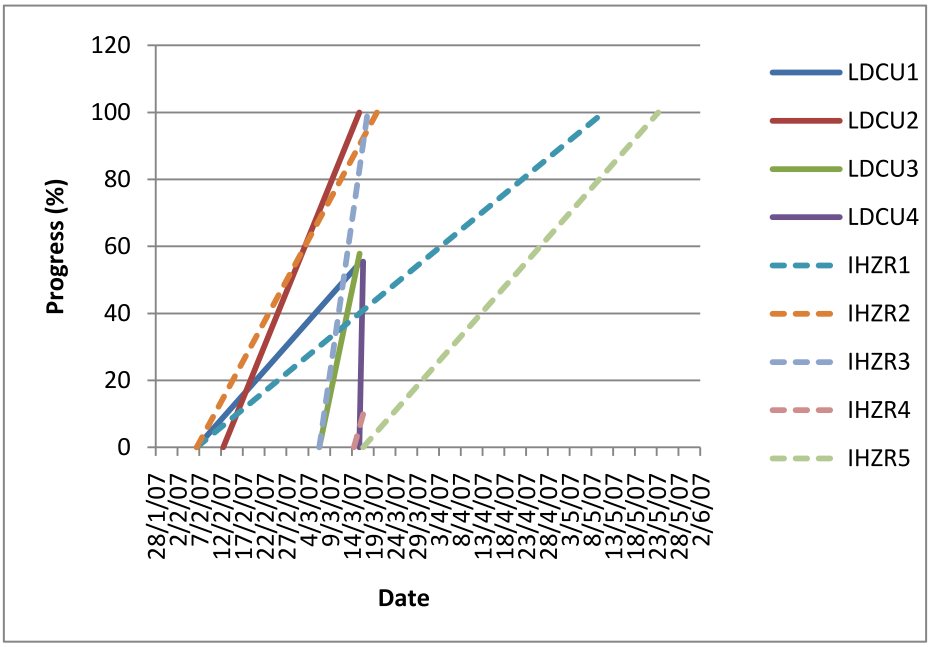


Figure 10.17 : Chart showing timeline for runs of Muck and Canal games for student #9

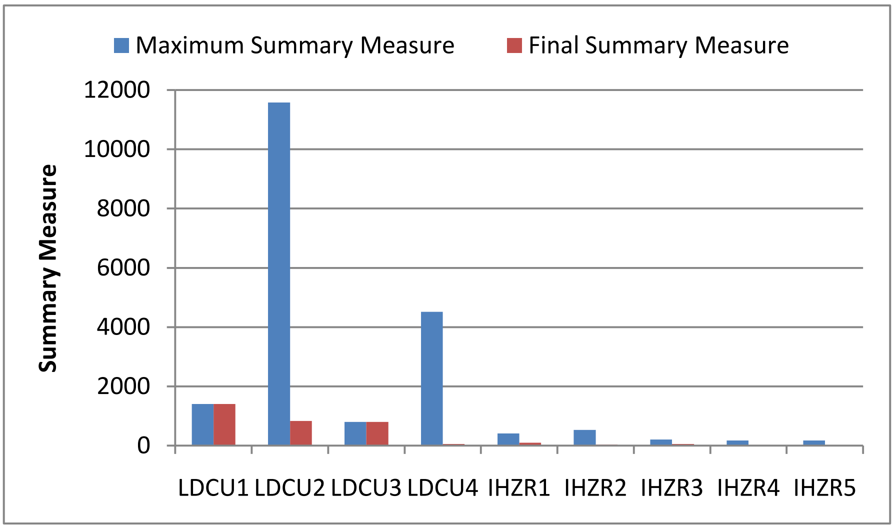


Figure 10.18 : Improvement in performance between Muck and Canal Games for student #9

Table 10.2 and figures 10.19-10.20 illustrate the improvement in performance for student #2 (user HQXE in the Muck Game and user AFAI in the Canal Game). Table 10.2 presents the data in the order that the student started the games.

The student shows less inactive periods in their first run of the Canal game over the initial run of the Muck game. Once running the canal simulation the user does not interrupt the simulation to consult the reports as much as the Muck game or stop for *thinking time*.

User	Start	End	Time Spent	Days Taken	Profit	% done	Plans	Daily Progress
HQXE1	13/2/07	20/3/07	636	215	-2,100,252	71.2	7	0.33
HQXE2	20/2/07	06/3/07	654	219	-1,710,675	84.7	4	0.39
AFAI1	20/2/07	13/3/07	298	411	214,037	100	2	0.24
HQXE3	06/3/07	19/3/07	331	121	173,878	100	2	0.83
HQXE4	09/3/07	20/3/07	136	121	312,026	100	1	0.83
AFAI2	13/3/07	16/3/07	387	346	-548,346	64.8	2	0.19
AFAI3	16/3/07	20/3/07	281	429	2,618,659	100	1	0.23

Table 10.2: Gameplay data for student #2

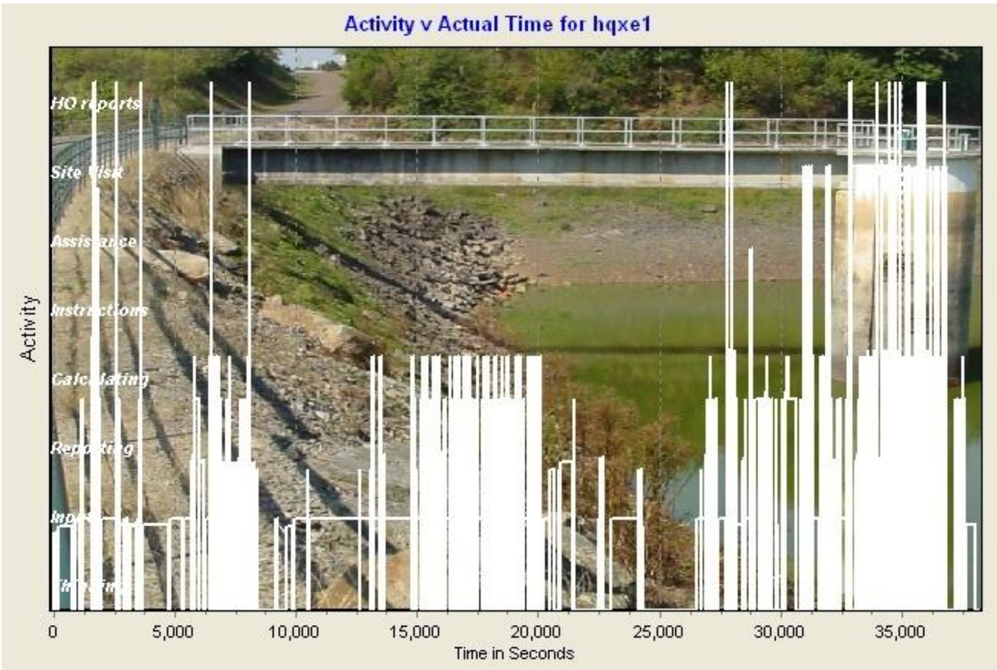


Figure 10.19: Activity Chart for first run of user HQXE (Muck Game)

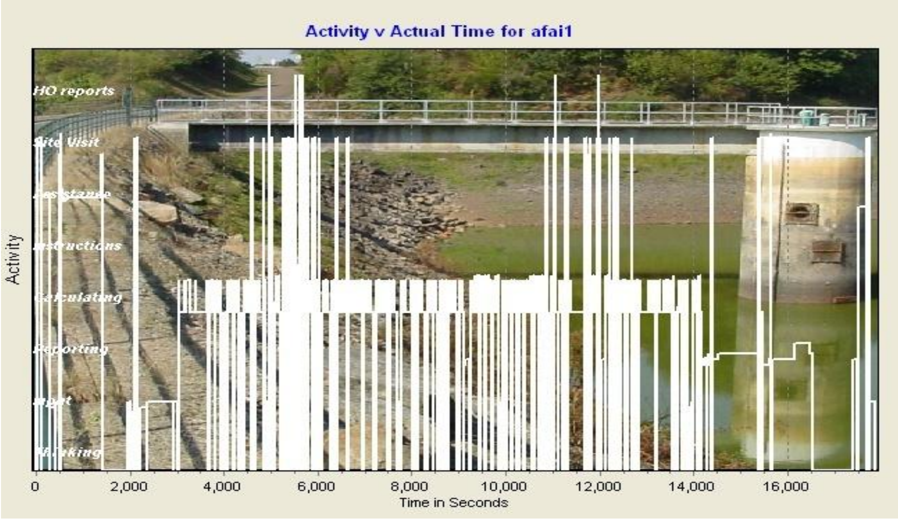


Figure 10.20: Activity chart for first run of user AFAI (Canal Game)

Too little evidence exists to show the same thing with students who ran the canal game first followed by the Muck Game. This is because very few students actually worked this way.

One example of a student who did complete the Canal game twice before attempting the Muck game is student #10 (Year 3 Muck=CTHM Canal=JTDX). There is some evidence that their experience with the Canal game helped their performance at the Muck game but it is inconclusive. The evidence for this conclusion is that they completed their initial Muck game (many did not), they were 2nd in terms of profitability for the initial attempt and they spent considerably less time in completing this initial attempt. This is illustrated in figure 10.21)

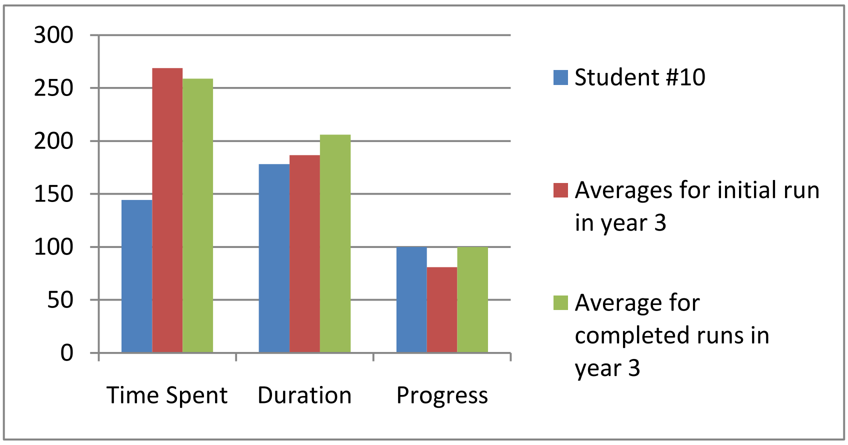


Figure 10.21 : Selected performance measures for initial attempt at Muck game for student with previous experience of competing Canal game (student #10)

Their performance at the Muck game in terms of profitability and their rate of progress also shows higher than average ability as can be seen in figure 10.22 which also provides data from their second and third runs of the game and the respective average values for benchmarking.

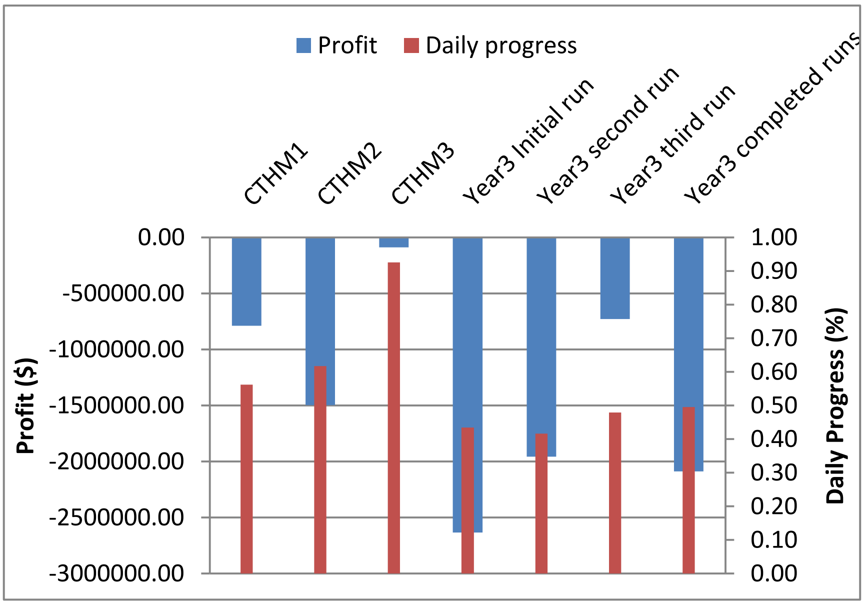


Figure 10.22 : Comparison of profitability and rate of progress for Muck game runs by student #10 against average values

A decline is seen is run 2 which cannot be authoritatively explained from the data shown but may be due to reduced time spent on that run of the simulation (5th shortest time spent completing the simulation in year 3 and the shortest completion time in run 2). However, even with this decline, performance for all three runs of the muck game are significantly above average for that run and for completed games.

By looking at the relative position or ranking of student #10's performance in terms of profitability in table 10.3, it does seem evident that their Muck game performance is improved over their Canal game performance. This would seem to indicate that their prior experience with the Canal game increased their performance at the Muck game.

Username	Game	Order Played	Ranking by run number	Ranking by run number (completed games only)	Ranking within all completed games
JTDX1	CANAL	1ST	6/19	6/12	21/36
JTDX2	CANAL	2ND	7/15	7/13	18/36
CTHM1	MUCK	3RD	6/18	2/10	15/36
CTHM2	MUCK	4TH	9/15	5/11	21/36
CTHM3	MUCK	5TH	3/15	2/11	3/36

Table 10.3 : Relative ranking of student #10 performance for all games played in year 3

However, from a single case study it is not possible to confirm if the higher than average is due to their previous experience with the Canal game.

10.5 Group based versus solo learning

Many students choose to work with their peers in small groups, usually of 2-4. The extent of group based play can range from total partnering on a single run of one of the students at a time to a loose collaboration and sharing of findings where each student still plays his own game. No effort is made to either encourage or prohibit such behaviours amongst students. In fact, due to the student's freedom to play the game at any time on the LAN it would be impossible to police such behaviour. The only limitation imposed in this regard is that students must complete at least one run of the games in order to be able to report on it for the coursework element of the module.

When working as a group, students adopt either a collaborative approach or competitive one. In the collaborative approach, students group together to make joint decisions on a particular project. They analyse the data together and act as a management team in the planning and control.

In the competitive approach, the students in the group work as individuals managing their own projects but they share their experiences on the work at very regular intervals.

It is not possible to collect quantitative data on the performance of individuals and groups without being too intrusive and altering the learning environment. However, observation would suggest that students who work in groups of either type have a better understanding of the games and achieve the module learning outcomes much better than the students who work alone. This is probably because of the increased engagement and reflection brought about by the discussion between group members.

The students and academics involved in the module thought this 'forced reflection' was so useful that they introduced group presentations into the fourth year of operating the module as described in section 8.7.4. It was observed that performance and learning improved significantly after the presentations even for those students who worked alone.

10.6 Indicators of difficulty

Although the games are designed and used as learning tools, it is very important to recognise that some students have difficulty relating to them and achieving the desired learning outcomes. It is necessary to identify these students and to intervene to assist their learning.

Experience in using the Muck and Canal games over a number of years and feedback from the weekly ACPM clinic sessions lead to the identification of the students experiencing difficulties in completing the simulated exercises. Analysis of their in-game performance highlighted behaviour patterns that indicated when they were having difficulty. These are shown in table 10.4.

Indicator	Description
Significant underperformance	The most obvious example of difficulty. This can be indicated by high summary measure values, excessive spending and low rates of construction. Any underperformance is assessed in terms of the statistical measures on student performance obtained from previous operation of the module.
Lack of improvement in subsequent runs	A lack of improvement across runs is an obvious sign of difficulty. As shown in chapter 9, student performance shows improvement on repeated attempts at completing the simulation and this is especially true in the transition from the first to second runs.
Repeated change of resource types	Analysis of student data indicates a strong correlation between this indicator and poor performance. The high cost of repeated changes to resource types demonstrates desperation or a lack of understanding of the rules of the simulation. Conversations with students showing this behaviour backs up this conclusion.
Excessive re-planning	Another sign that a student is encountering difficulty. The degree of re-planning should be assessed against typical measures for the run attempted and there should be a reduction in re-planning in repeated attempts at the simulation. It is not unusual for a student to require the maximum number of plans in their initial completion of the games but this should be reduced in subsequent attempts.
Repeated change to haul road gradients	This could indicate signs either of experimentation or desperation with the latter being most common. Students are free to alter the haul road gradients during the simulation but there is a strong correlation between repeated change and poor performance. In discussion with students behaving in this manner, it was confirmed in most instances that their changes to the gradients was an act of desperation rather than a well thought out strategy at improvement. An example of experimentation rather than desperation is given in section 10.2.3 for student #3.
Repeated failure to complete	Failure to complete after a series of attempts is a clear sign of poor performance and is often related to students being unable to overcome the introduction of poor weather in the simulation. This indicates that the student has failed to understand the full effect of rainfall on haul road state and how to solve this issue.
High levels of concurrent play	Concurrent operation of a number of runs is often a sign that a student is experiencing difficulty. Analysis of the data acquired shows a strong correlation between encountering performance problems and starting a new attempt at the games. If this behaviour is repeated it indicates that the student is unable to solve a performance problem and has not understood the reasons for their failure in the previous attempt.

Table 10.4 : Indications of difficulty identified in the ACPM module

In addition to those behaviours described in the table there is obviously the direct communication of difficulty from the student either in person at the weekly clinics or via the in-game messaging system. It should also be noted that there are instances where some of the types of behaviour described do not indicate student problems are instead signs of active experimentation by the student. This is to be encouraged but it is still important for teaching staff to clarify the reasons for any anomalous in-game behaviour.

The ability to identify, and possibly predict, where a student is experiencing difficulty in completing the simulation game is potentially a very powerful aid to teaching and learning. Greater teaching support can be applied to those students in an attempt to help understand the source of the student's difficulty and to help them overcome their problems.

10.7 Summary

This chapter has illustrated key findings from the research in terms of the behaviour patterns and learning styles adopted by typical students during the research trial undertaken with the ACPM teaching module. A small number of students were selected from the four years of running the module to demonstrate specific points.

A number of learning styles were outlined that represent the behaviour of the majority of students in using the two simulation games used. In reality, students will often adopt one or more of these strategies to some degree throughout their progress on the teaching module. It has been found that most students will show a preference for a particular strategy of learning. Student activity during gameplay was illustrated with a number of examples that showed changes to their behaviour on repeated play and across the two games.

As stated in chapter 3, simulations and games have issues in enabling student reflection on the learning experience. Some examples of student reflection from the use of the Muck and Canal games in the ACPM module were given. These were based on student responses to the in-game feedback exercise. This demonstrated how the data collected might be used to both to monitor and encourage reflection on the learning experience.

One of the principal aims of the research was to investigate the degree to which any learning gained through simulations and games might be transferable and the extent to which students are achieving their learning outcomes rather than simply learning to play the game. This was investigated in chapter 9 using statistical measures obtained from all students monitored. In this chapter individual examples of students who played both games are used to show that lessons learnt in the Muck game are useful in the Canal game. The reverse also appears to be true but the evidence for this is very limited as the vast majority of students play the Muck game before the Canal game.

Anecdotal evidence and results of student assessment have shown that those students working in groups generally perform better than those working alone. It is hypothesised that group working by its intrinsic nature will create greater reflection on the lessons learnt due to interaction and discussion between group members. By introducing aspects of competition or collaboration to the use of the simulation games, group working can also increase student engagement.

When using simulation games in a pedagogic role it is important to identify not only where learning is occurring but also where students are struggling or failing to learn. Early identification of learning difficulties can ensure that additional teaching support can be applied. It may also be able to identify a particular aspect of difficulty encountered by a student, e.g. poor planning or micromanaging, and focus support on that aspect. A range of such indicators for the ACPM module were identified and were used during the operation of the module to assist students in effective achievement of the learning outcomes. The extensive data tracking and monitoring processes made possible by this type of learning are essential tools in supporting this type of unsupervised and self-directed learning through simulations and games.

11. Conclusions

This section summarises and concludes the thesis. There is a brief introduction and review of the objectives of the research after which conclusions relevant to those objectives are given. Other conclusions that emerged during the work but were not directly related to the research objectives are then proposed. Future work to further extend the research in terms of both the design and development of simulation games and in the design of teaching methods to exploit their use are then discussed briefly.

This work has enabled two types of conclusion to be drawn: Those directly related to the objectives and those which arose from the work but which were not envisaged by the objectives.

11.1 Discussion of and conclusions drawn in relation to the stated research objectives

As stated in section 1.2, the primary research aim of this work is specifically:

> *"To quantitatively and qualitatively evaluate the usefulness of simulation games for teaching construction management skills"*

The work done as part of this research and described in chapters 8-10 satisfies the research aim and is supplemented by the additional work outlined in chapters 4-7. Chapters 9 and 10 drew on the large set of quantifiable data collated and analysed from the ACPM module. It was shown how such data can be used to:

1. Assess learners' improvement on repeated play of a simulation game. Numerous examples of this are given in the analysis of the overall dataset in chapter 9 and in the examples of individuals' improvement on repeated attempts are shown in chapter 10.
2. Compare student performance across two simulation games and therefore examine the transferability of skills learnt through the use of simulation games.
3. Identify students encountering difficulty in achieving the learning outcomes through the analysis of key variables of a simulation game. This is of particular interest as it can be used to identify problems early in the learning process and intervene to assist student learning.
4. Integrate with standard qualitative data assessments such as student questionnaires and interviews. This combinatory approach can be used to provide a broader and more detailed assessment of student

understanding and learning. See for example section 8.5.2 and section 9.4.1.1.

This primary aim is also achieved through the successful completion of the more detailed research objectives, also outlined in section 1.2. The results and conclusions for each of these are given in the respective sub-headings that follow.

11.1.1 Investigate the use of simulation and gaming for learning

Research into the areas of teaching and learning processes and computer based simulation and games for learning, described in chapters 2 and 3 respectively, demonstrated how simulation games can be used to promote effective learning. More specifically, how the work of Kolb, Papert and Piaget (Kolb, 1984; Papert, 1980, Piaget, 1952) amongst others showed the potential for the use of simulation and games are a teaching tool. More recent studies highlighted the successful use of simulation and gaming for the teaching of construction management (see section 3.7.1).

Practical research outlined in chapters 4 to 10 showed that simulation and gaming can be an effective learning method especially in the teaching of management methods that are not easily transmitted through traditional teaching approaches. Some specific findings from the research are summarised below:

- A simulation game capable of modelling any business or project specified by the students can be an engaging and useful learning exercise. It allows the students to reflect on their business or project plan (chapter 6).
- A teaching module utilising just simulation games as the teaching medium can be a useful and engaging exercise for students though it requires students to be highly self-motivated and requires a sufficiently complex and repeatable simulation game (chapter 8).
- It is difficult to compare performance at traditional assessment exercises with performance at running a simulation game (chapter 9).
- Software for managing and monitoring students' use of simulation games can be used to enable them to be used in self-directed learning without supervision (Chapters 5 and 8).
- Monitoring of student activity during a simulation game has been shown to be a highly effective method for assessing the performance of students and their learning styles. (Chapters 9 and 10). This leads onto the next research objective.

11.1.2 Identify styles and methods of learning employed by students using simulation games in an educational context

Research on theories of learning (shown in chapter 2) identified potential learning styles employed by learners. Results from the implementation of educational simulation games described here showed some correlation with this research and identified specific methods employed by students in the ACPM trial (Chapters 9 and 10). For example, the use of trial and error, extensive pre-planning and sensitivity analysis by students were all shown in Section 10.2.

Qualitative feedback from questionnaires, interviews and observation of students during the clinic sessions also highlighted specific styles of learning that could not be identified from the analysis of the quantitative data collected such as the prevalence and effect of group based versus solo learning (see section 11.2.7 for further details)

Repeated play by subjects in the ACPM teaching module was a highly effective method for the identification of learning methods and styles as it enables comparative analysis between attempts to be carried out. It also produces a richer set of quantitative data than would be obtained with only a single play-through.

11.1.3 Investigate the utility and applicability of quantitative and qualitative data in evaluating student learning through simulation games

The use of qualitative evaluation of student learning is well established in the existing work in this area (chapter 3) and similar assessment methods were employed in the practical research carried out. Results from student feedback, questionnaires and interviews were essential in the evaluation of learning. Illustrations of this are given in sections 6.4, 7.2.3, 7.3.2 and 8.6.1. Detailed analysis of qualitative feedback from the ACPM module is provided in sections 9.7 and 10.3.

Quantitative data collected during the ACPM module through the MCG Umpire tool was a key feature of this work. It provided an objective method for quantifying student performance and improvement at the simulation games. Chapters 9 and 10 focus on this data and showed how it can be used to assess learning.

The combination of the qualitative and quantitative datasets provided a much improved method for evaluating learning through simulation games than traditional approaches. Qualitative feedback from students can be compared with the quantitative monitoring data collected to assess the veracity, importance and any potential impacts for learning arising from the feedback.

For example, a common form of qualitative feedback from students is in relation to the accuracy of the output from the simulation against their own calculations. Quantitative monitoring data can be used to confirm the veracity of the simulation (or to identify any errors in the simulation on rare occasion) and be used to cause the student to reflect on the reasons for any discrepancy such as the quality of the input data they are using for their calculations.

Both qualitative and quantitative data has its role in the assessment of the learning process and the work described in this thesis has highlighted the potential benefits from the acquisition of quantitative data on student performance which is often neglected in other studies within the subject domain.

11.1.4 Provide guidance on the design and development of simulation games for learning

Lessons learnt in the development of the simulation games BizSim, SubCon, Muck Game and Canal game are described in the relevant chapters (chapters 4 and 5). Feedback from students during the various trials (chapters 6, 7 and 9) highlighted aspects of game design that could be improved.

Students were not overly concerned with the lack of graphical content in the games (which was unexpected) but indicated a need for greater feedback and control (or agency) over the simulation games in general. This is a typical complaint in regard to the use of management type simulation games. Players tend to expect complete control of the simulated environment and become frustrated at negative events which they feel are outside their control. However, in terms of the realism of simulation and the effectiveness of the learning experience it is important that player agency is limited (see section 3.5) even though this could reduce engagement. This problem can be reduced through effective in-game and classroom feedback mechanisms.

It was also concluded that the verisimilitude of a simulation is not a significant factor in learning provided that it is a sufficiently convincing depiction from the student’s perspective. This is borne out by the fact that students did not notice or appreciate any difference in the simulation models between the Muck and Canal games although the Canal game is actually a more accurate simulation of earthmoving processes and the equipment involved.

Repeated play of the Muck and Canal games during the ACPM module highlighted a need for greater stochastic variation during repeated play or the introduction of additional simulated scenarios to avoid a drop in player engagement due to over-familiarity with the content. This issue is discussed further in section11.3.1.

11.1.5 Investigate the balance between realism, game difficulty and learning outcomes in an educational simulation game

It was discovered from research of existing work (chapter 3) and from the development of simulation games (chapters 4 and 5) that compromises must be made when developing educational simulation games to create an effective and engaging game. The degree of verisimilitude in the simulation must be balanced with the needs of the learning outcomes and rules of game design.

For example, the Muck and Canal games described in chapter 5 allow players to request and receive plant equipment instantly whereas; in the real world there may be a delay between requesting and receiving equipment. Since the delay is outside the control of the player and is not easily planned for it would be poor games design to include such a frustrating element of gameplay. Another example from the BizSim game would be that marketing is simplified to an overall budgetary figure rather than the assignment of specific marketing strategies. In both instances the realism of the simulation has been reduced slightly in order to produce a more engaging learning experience. Such changes can also reduce the difficulties of developing the simulation game. This is a particular issue in terms of BizSim where the simulation model must be generated within a short timescale due to the teaching constraints of the STaB/MPT teaching module.

Focus should be on the learning objectives as the primary requirement. The simulation should represent a version of the actual experience that is representative but removes some of the frustration and lack of agency in the real world in order to introduce gaming aspects and increase student engagement. The simulation games developed did not have fixed objectives like a typical game and it would be an interesting experiment to introduce fixed goals (e.g. Achieve a certain profit level) to see any impact this might have on learning and engagement.

11.1.6 Retention, application and transferability of learning through simulation games

Retention of knowledge acquired through simulation games has been investigated by Schaffer (Schaffer, 2006a; Schaffer, 2006b) through the use of follow-up interview exercises and was discussed in chapter 3. It was not possible to examine the retention of learning in the work described here as students were not available for follow-up interviews or other methods (e.g. additional attempts at the simulation games). This could be an area for further work.

Application of learning was assessed through the repeated play of the simulation games described in chapters 9 and 10. Improvement in performance was clearly shown (see for example tables 9.11, 9.13 and figures 9.14, 9.16-9.18 for the overall dataset and student case studies #1 and #2 from sections 10.2.1 and 10.2.2 respectively) indicating that students are able to apply the knowledge learnt in initial attempts at the simulation game in their later attempts.

Transferability of learning was investigated through the introduction and use of the Canal game which represented a different scenario (increasing project scale and non-linearity) but similar processes and interface. Evidence was found that showed a definite improvement in Canal game performance for those with experience at the Muck game even discounting for differences in the relative difficulty of the two times. There was not enough evidence available to identify if the converse was true as few players attempted the Canal game prior to the Muck game (even though this was possible).

11.2 Conclusions surplus to the objectives

In carrying out the work the following conclusions have been drawn that do not map clearly onto the two sets of objectives defined during the early stages of the research.

11.2.1 The use of an Umpire type tool to manage the use of simulation games in learning

The development of the MCG Umpire was initially required to run the Muck and Canal games across a computer network (see chapter 5). However, it proved to be a very useful tool for a number of reasons including the monitoring of student progress and providing an additional communication and feedback mechanism. Having developed a number of simulations and run them in an educational context as part of this research, it can be concluded that having the facility to save and access monitoring information is an essential feature of any educational game. This might be achieved through an add-on package such as Umpire or might be built into the game.

11.2.2 IT/Technical Issues and their impact of teaching

As discussed in chapter 8 (section 8.7.1), IT and network related problems were identified as a significant issue where teaching requires the use of computer based simulation games operating across a network. These issues were not related to the games themselves and, though eventually resolved, had an effect on the teaching process. When planning to use simulation games in teaching, it is recommended that teaching staff develop contingency plans to deal with the potential for IT related problems.

11.2.3 Difficulties in assessing learning

Though much research was done in this area and plans for collecting quantitative and qualitative data were executed successfully, it proved to be difficult to firmly establish the extent of learning occurring through the use of simulation games. There is clear evidence that learning occurred and feedback and anecdotal evidence confirms this. However, it proved to be difficult to quantify the extent of learning and be able to directly compare learning between students.

It is thought that the use of blended learning and specifically the use of traditional assessment methods in the ACPM module were responsible for this difficulty. In the STaB/MPT modules the nature of the coursework exercise and the small number of students are responsible for the inability to quantify any learning occurring through the use of BizSim.

11.2.4 Discovery of alternate methods of running simulation games for learning

A variety of methods for using simulation games for learning were investigated as part of this research. It was shown how a single game (the Muck Game) can be:

- Used in a variety of roles - team based game, solo game, supervised, unsupervised, distance learning, classroom learning, industrial training course, academic teaching module or coursework exercise.
- Aimed at a range of different academic levels – starting engineering students (section 7.3), Masters level students (section 7.1, chapter 8) and graduate engineers.
- An internationally useful teaching tool – it has been used across the world in short courses and extensive trials in UK, Netherlands and Australia were highlighted in this work.

It was found that the flexibility of the simulation game was critical to its ability to be reused in these ways. Changes to the Muck game made during this research such as the introduction of the defaults settings file and the MCG Umpire tool greatly increased its potential as a teaching tool. The development of the Canal game as a alternative (yet similar) simulation game also increased the potential learning that could be carried out and allowed the expansion from a coursework exercise or short course to a full teaching module.

11.2.5 Effect of student background on experiential type learning

Observation, results and feedback from the ACPM teaching module identified a number of effects of student background on learning primarily through the use of simulation games:

- Previous Industrial Experience – students with previous experience in the construction industry were found to be more adept at the simulation games and indicated a preference for this type of learning over traditional approaches though they were more aware of the compromises made to verisimilitude of the simulation aspects of the simulation games.
- Cultural Influences – It was noted that students whose cultural backgrounds tended to adopt traditional teaching approaches more heavily encountered difficulties in learning. This was particularly noted in year two of the ACPM module where the large class size reduced the level of teaching support available to each student. For students with this cultural background it is thought that the addition of more traditional teaching content and less student led learning would be beneficial.
- MSc versus MEng students – In general, it was found that MEng students performed more consistently than MSc students. However, it was often MSc students who produced both the best and worst performance at both the simulation games and assessment exercises.

11.2.6 The utility of blended learning methods

In the ACPM and STaB/MPT modules described in this thesis, the combination of experiential learning with traditional assessment (coursework and/or examination) was employed. Institutional regulations were partly responsible for this use of blended learning but it was also used to investigate its capabilities. Benefits found include:

- Familiar methods of assessment meant that students were not overwhelmed with new teaching practices.
- Assessment procedures were in line with other teaching modules on the course and were acceptable to accreditation bodies.
- The provision of additional learning benefits that could not be realised through simulation games, e.g. report writing, communication skills and self-motivated research.

- The opportunity for students who were not suited to or comfortable with experiential learning methods to use traditional teaching approaches (self motivated) to complete the assessment.

However, the use of blended learning did introduce a number of problems and difficulties that were not fully anticipated:

- Lack of link between simulation game performance and assessment procedures
- Increased difficulty of quantifying any learning that was caused by the use of the simulation games.
- Bias towards students who perform well at traditional assessment methods. Students could learn a great deal from the use of the simulation game and still perform badly at the assessment stage.

11.2.7 Repeated versus single play

Iterative play of a simulation game has been shown to be highly useful when attempting to quantify student performance at a simulation game. It provides a baseline measure of performance and can be used to track improvements in student understanding. Evidence for this can be found in chapters 9 and 10.

For a complex simulation game such as the Muck or Canal game, repeated play is often necessary for a student to fully appreciate the workings of the simulation, to be able to produce an optimised solution and to achieve all the learning outcomes it can potentially deliver.

However, it has a significant limitation which is especially apparent for the more able students. Familiarity breeds contempt and repeatedly playing a game that is highly deterministic will reduce engagement and lead to boredom.

Single play of a simulation game has also been shown to be an effective teaching tool as demonstrated by the use of the BizSim simulation as a coursework element in the STaB/MPT modules (chapter 6) and the use of the Muck game during the teaching module at Curtin University (section 7.3). Single play reduces any boredom that can result from over familiarity with repeated play of a simulation game. It also reduces the effect of learning the game over learning the required teaching content that could set in through repetition. Repeated play of a simulation game could lead to students accepting the simulated version of reality which could be misleading due to the inherent compromises made to reality in any simulation of it.

However, aspects of learning could easily be missed on a single attempt at a game. This is particularly true if the game and/or its interface have a noticeable learning curve for their successful operation. It is possible that a student spends too much of the simulation learning how it works.

Results from the work done indicate that a balance between repetition and single play based on the learning requirements is the most appropriate method to follow. *Repetition with variation* would seem to be an ideal compromise to balance the needs of students, learning requirements and research and assessment exercises depending on the specific situation. How this might be achieved is described in the section on future work (see section 11.3.1)

11.2.8 Group based versus solo learning

There is anecdotal evidence that students working in groups perform better at simulation games and in achieving learning outcomes. This is also backed up by student feedback. Both competitive and collaborative modes of group working were identified and both seemed to be effective methods for group working. The choice of competitive versus collaborative group working seems to be determined by the learning style of the individuals within the group and by group dynamics.

Solo use of a simulation game was also shown to be an effective learning mechanism though it can lead to problems for students who encounter difficulties in operating the simulation game and can become frustrated.

11.2.9 Use of bespoke games versus off-the-shelf games

The use of the commercial SESAMEE simulation game described in chapter 6 provided a method for comparison between bespoke and off-the-shelf games. It was found that commercial software offers a number of advantages including the elimination of lengthy development times, a professional interface and a fully tested and tried simulation game. However, it is often costly, inflexible and is not designed specifically for the purposes of the teaching module.

Bespoke game development is time consuming and is not typically capable of producing as robust a simulation game as a commercial game but it does enable the alignment of the simulation game design with the learning objectives.

For the purposes of the STaB/MPT modules (see chapter 6), commercial software would not have been capable of modelling student business plans and therefore was not suitable for the purposes of that module. SESAMEE was found to be a useful learning tool but student feedback indicates that additional learning was achieved through the use of simulations of the students' own business plans in BizSim.

11.3 Future research in simulation game based learning

This section describes potential future research in terms of the teaching and learning experience when using simulation games. It describes a range of potential changes to the way in which the teaching methods can be altered to improve learning.

11.3.1 Matching difficulty to ability / Variation in repetition

Repeated play of the Muck and Canal games was useful from both a research and an educational perspective. However, it was discovered that repetition reduced engagement for the more able students due to over-familiarity.

By introducing a range of projects scenarios that are aimed at different levels of attainment and specifically designed to examine key issues in construction management such as health and safety issues or profitability it could be possible to improve the learning experience and more closely match learning content to student ability.

Game-like objectives could also be introduced in some scenarios in order to further test those students who have already completed the simulation games to a satisfactory level of performance.

It is thought that these types of changes to the core gameplay and the additional scenarios for simulation would greatly extend the ability of the games to withstand repeated play by students.

11.3.2 Introduction of temporal constraints on gameplay

It was noted during the analysis of student activity over time (chapters 9 and 10) that students tend to play the game to suit their own timescale and their workloads. They have complete control over the advancement of the simulation and are therefore not subject to the time pressures that would exist in a real construction project. They are able to stop time whenever they wish and advance time at a rate that suits their needs. This could be seen to reduce their need to reflect on their simulated experience and the importance of reflection was highlighted in chapter 2 as an essential requirement for learning. This is good from the point of view of 'game playing' and hence, perhaps in maintaining the interest of the player. However, it does not model many of the pressures of a real project in which decisions have to be made in real time to deal with a situation which arises.

Another learning method using the simulation games is therefore actively being considered. In this, the game will be used on a real time/factor basis. For example, every real hour would be made equivalent to one simulated day (A factor of 24). This would mean that players would have 280 hours (approx 12 days) to run a 40 week dam game. The purpose would be for players to appreciate the need to work and act while time passes i.e. decisions have to be made not put off. This could be considered to be a 'simple' learning-by-doing experience akin to the existing fact of life that you 'cannot turn the clock back' that is built into the Muck game in its current mode of operation. This 'lesson' addressed here is that 'time waits for no one'. In addition to this the developers have found that the players, when given total freedom, tend to put things off as long as possible and then rush (without due monitoring and review) to finish the project. With a time-base the clock will be running and they will not be able to concertina the important stages as they will not be able to stop time passing i.e. passage of time will be linear rather than accelerated towards the end of the real time period. A final benefit to the controller is that the time for the game can be controlled. The only problem will be the 'wee small hours of the morning' but knowing how students sometimes work through the night (or at least late into the night) the days (= real hours) when they cannot make decisions will be small and such periods can be easily accommodated. Obviously for short courses, the time factor can be adjusted to suit the duration and speed of the course.

11.4 Future work in the development of a more complex simulation game - the Building Game

The Muck and Canal simulation games are based on 'traditional' civil engineering projects. Whilst the methods examined are relevant to all types of project and particularly to all construction projects, some criticism emerged from professional engineers working mainly in building. For this reason, a 'Building Game' is being proposed.

This game follows a similar format to that of the Muck and Canal games but is based on the construction of a multi-storey in-situ reinforced concrete-framed building. A screen mock up of the initial screen for this project is shown in Figure 11.1.

Figure 11.1: A mock up screen showing the Building Game initial screen

Each floor of the building has a similar construction process as illustrated in the network shown in figures 11.2 and 11.3 (although these are from the proposed planning and control sections of the game they are used here to represent the general project construction method).

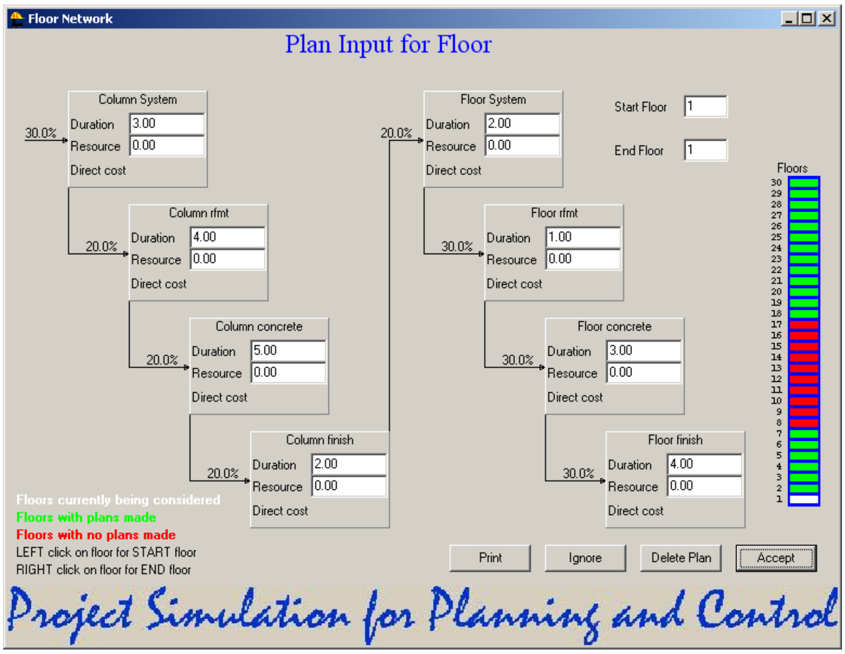


Figure 11.2: A mock up of the Network for the Construction of a Floor

The player will have to select the resources to carry out the various activities on each floor. The production rates of the resources need to be balanced across all the activities of a floor and the production rate of the floors has to be sufficient to achieve the overall targets set by the client and reflected in the plan. Several different construction 'systems' will be available and will be reflected in the resources selected by the player.

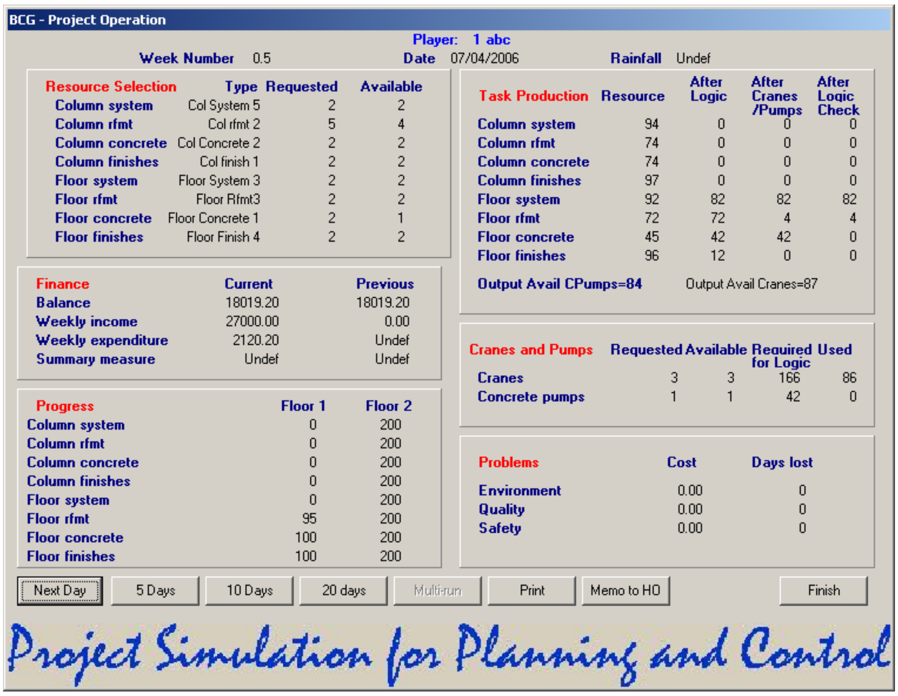


Figure 11.3: Screen mock up showing Resources and Progress

This gameplay will be considerably more complex than in the Muck and Canal games largely because of the number of different activities on each floor and the number of resources that are required to carry them out. (In the original games there were 6 activities – excavate rock, excavate clay, transport rock, transport clay, fill rock, fill clay – with 'similar' resources operating on rock and clay. In the building game there will be 8 activities all with very different resources and with more complex logical relationships between them).

The interface between the player and the game will have to be made more user-friendly. An illustration of this is in the use of bar charts and line-of-balance diagrams to both input and output plans. These are illustrated in Figure 11.4.

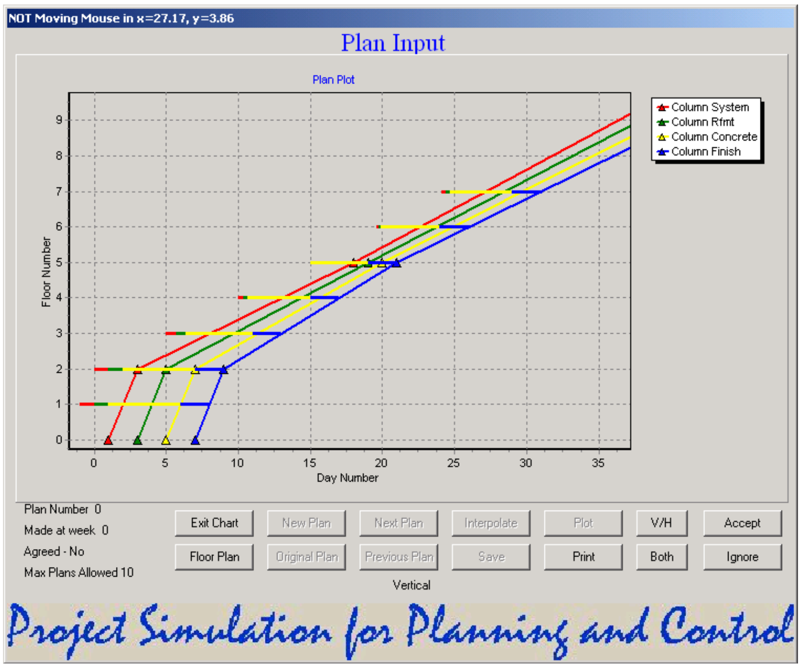


Figure 11.4: A mock up of a typical Planning User Interface

11.5 Final comment

This thesis has addressed the objectives and met the overall aim of the project, namely to quantitatively and qualitatively evaluate the usefulness of simulation games for teaching construction management skills. Issues arising during the research have been investigated and discussed. Future work has been identified and in some cases already started.

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Appendices

A. SESAMEE business simulation game

SESAMEE is concerned with a small business producing gas detection equipment. It uses data gathered from an actual business to model the simulation and focuses on the development of the business from start up until the end of year 2 or from year 2 onwards. For the purposes of STaB it was decided to use the startup to year 2 scenario. This allowed the students to examine the next stage of business development after having a business plan accepted. Example screenshots from the SESAMEE game are shown below.

Figure 11.5-1 : Tutor's Menu (simulation set up options)

As can be seen in Figure 11.5-1, SESAMEE provides a large range of options for the tutor in terms of customising the settings of the simulation though the simulated company and environment are fixed. An example of the extent of the options to adjust the simulation can be seen in Figure 11.5-2. It enables the tutor to specify the impact of staffing levels on the staff contribution to overall company performance within the simulation. This contribution can also be specified and altered under the *weighting factors* tab that can also be seen in Figure 11.5-2.

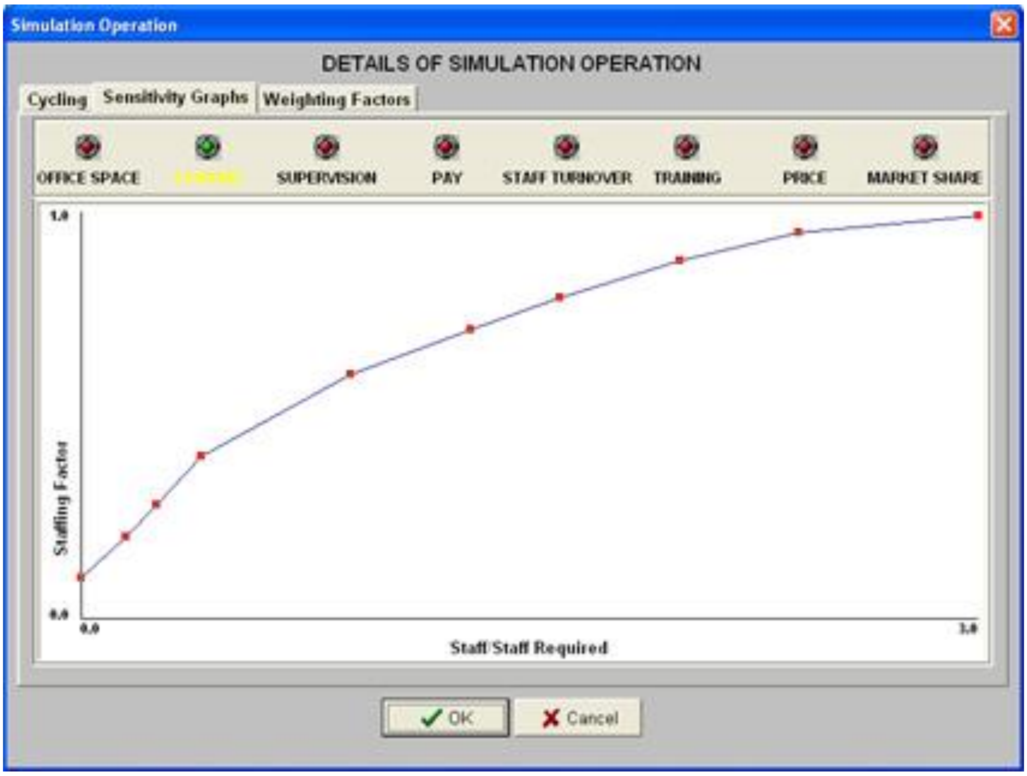


Figure 11.5-2: SESAMEE - Simulation sensitivity options for tutor

The simulation is flexible in its ability to alter the parameters of the company, markets and resources and products. However, it is not possible to change the fundamental nature of the company and its products themselves.

Figure 11.5-3: SESAMEE - Research & Development options

The SESAMEE simulation game itself works in a similar fashion to many of the business management simulations described in earlier chapters and the BizSim game that was created as part of this research and described in chapter 5. The player makes management decisions from a range of predefined options and reviews their progress through a range of reports and charts. The simulation is advanced manually by the player or automatically by the system until the end point of the simulation is reached. For the purposes of the STaB module the simulation ran for two years in monthly increments.

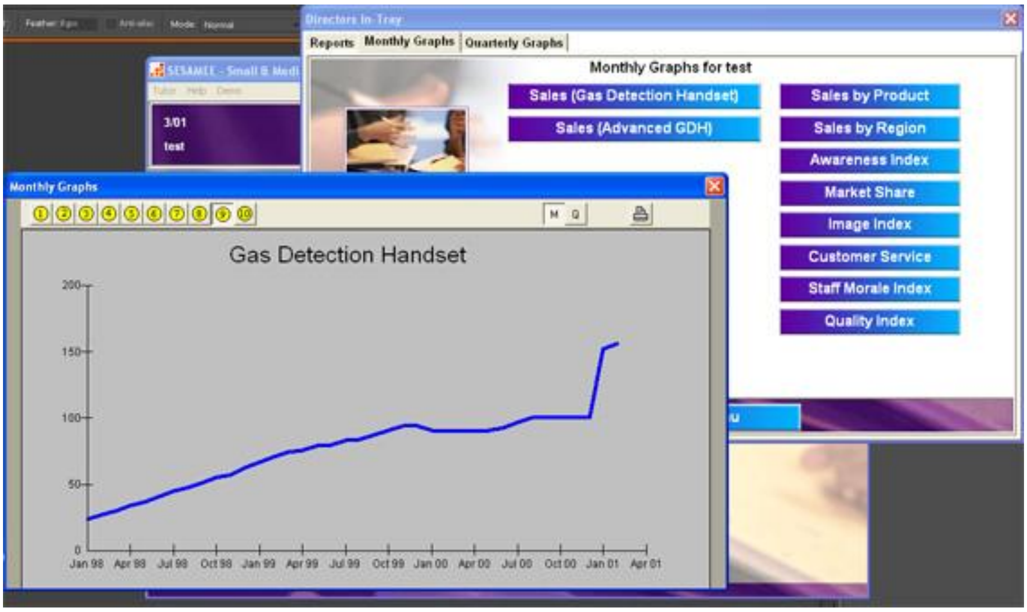


Figure 11.5-4: SESAMEE - Example Charting options

Figure 11.5-5: SESAMEE – Marketing options for player/student

B. STaB – Module Information Document

Module:	H2DV37 Science, Technology and Business
Sub-Module:	Business Simulation
Module Convener:	Dr M Smith
Associated Staff:	Dr M J Mawdesley
	Mr G Long

Aims:

The relevant aim of the module is: 'To introduce students to the importance of and the processes involved in the commercialisation of science and technology'.

Objectives:

In addition to the objectives for the overall module, this sub-module will enable students to ***gain experience*** in

- The development of business plans
- The use of business plans and control techniques
- The analysis and use of company reports and other information
- Timely decision making

Content description

The relevant section of the module content description is: 'The third part of the module involves taking the business idea further with the use of a computer based simulator / game.'

This game simulates the environment in which a small company is to start up and operate. Each student will work as a director to run the company making all the relevant decisions about planning and operation.

Method, frequency and timing of class

Following an introductory session, students will work individually to understand the environment and the company, to produce a plan for the company and to run the company through its first two years of operation.

Method and timing of assessment

The sub-module will be assessed by means of a report on the operation of the company over its first two years, the decisions you took and the reasons for them **to be submitted by 6th May 2002**. The report should be of the form you would give to an investor in the company.

Marks will be available for both content and style of the report.

This report will count for a maximum of 10% of the marks available for the module.

Feedback

The staff concerned with this sub-module value feedback. Please provide feedback directly to the staff concerned or through the normal feedback mechanisms.

Procedure to be adopted

- At the introductory session (which will include a demonstration of the simulation software), obtain a CD containing a copy of the simulation and floppy disk containing the initial scenario and an authorisation file.
- Load the simulation from CD onto your computer. It should autorun (if it does not, double click on the SetupTeam.exe on the CD). This will create a directory Sesamee under Program Files and a Program Menu item Sesamee. Within this Program Menu item there is an entry TeamSME which is the program to run.
- Place the floppy disk into the A: drive and copy the initial scenario file (called stab2003.sme) and the authorisation file (author.ize) from the floppy to the Sesamee directory.
- Run the program from the Start Programs menu to check that it works and contact us if not.
- Load the scenario from the **Tutor** menu **Load exercise** option using the file chooser dialog box. This will only operate for one week from the date of the introduction.
- Understand the company and the environment in which it is to operate
- Produce a business plan for the first two years of the company's operation
- Submit the business plan electronically to the module staff.

- Receive the main authorisation file for the simulation which will allow you to operate the company for two years (game time).
- Copy the authorisation file (author.ize) from the e-mail onto the same directory as the simulation and remove the old one.
- Operate the company for two years recording the information and making decisions as necessary. ***Stop when you have completed two years and Save the Exercise.***
- Produce a report (1000 words plus up to 10 tables / diagrams / graphs) on the operation of the company and submit it electronically. Submit the saved exercise file electronically.
- Hand in the CD and the floppy disk to the sub-module staff.

Recommended timing

1. Submission of business plan 1 week after introduction (19th April 2002). This is an estimated 10 hours of work.
2. Completion of simulation approximately 10 days after receipt of authorisation file (29th April 2002). This is an estimated 10-15 hours of work.
3. Submission of final report approximately 10 days after completion of simulation (6th May 2002). This is an estimated 10-15 hours of work. This final date is the coursework submission date beyond which University rules will be applied.

Important Notes:

1. The simulation will only run for 10 days at a time and will be set up such that it will not be possible to run it after 6th May 2002. The former is a limitation of the software; the latter is to avoid a clash between the demands of coursework and the revision for examinations.
2. Do not cycle through the simulation to see what happens. You will not be able to go back in time.
3. Do NOT use the Save Exercise option (except at the end of 2 years as described above) as this causes problems in the software. The current state will be saved automatically as you exit the program (by clicking in the top right hand corner of the screen).

Contact: **e-mail address:** Gavin.Long@nottingham.ac.uk

telephone: 0115 846 6055

C. Activity network for Tingham tank farm project

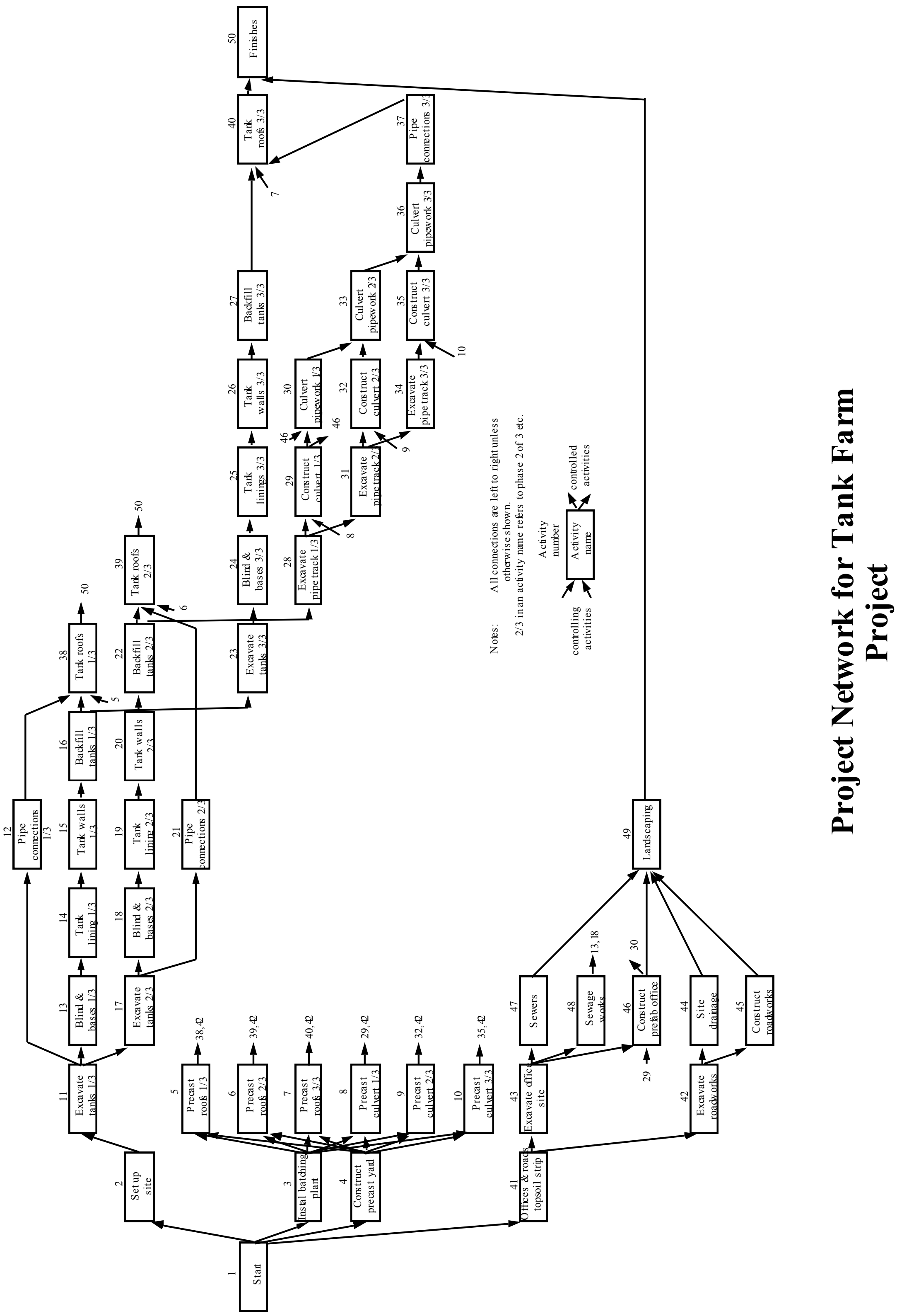


Figure 11.5-6 : Activity network for Tingham Tank Farm Project used in the trial of the SubCon simulation game

D. Curtin University of Technology teaching module description

CIVIL PROJECT ECONOMICS & GEOTECHNICAL ENGINEERING – 362

ASSIGNMENT : CPE – Dam Construction, Planning & Control

SPECIFICATION / BRIEF:

Your group has been appointed as engineers in charge of a Dam construction project. You are required to;

- Plan for the construction, rate of construction, equipment requirements and income and expenditure. Prepare appropriate charts and information sheets of planned productivity, cash flow and equipment/plant use.
- Have your plans approved.
- Undertake, monitor and control the [simulated] construction of the dam. As you proceed you are to keep a record of production, income, expenditure, plant/equipment utilization and productivity. You must record changes to the original plan and reasons for these changes.
- Prepare an oral and written report on the construction phase along with recommendations to be used when planning similar projects in the future.

You are expected to submit reports on the two phases;

- Construction plans [as per 1 above]. Appropriate charts, tables and data sheets and an oral report [max 5 minutes]
- A written report on construction, plan changes & recommendations [as per 3 & 4 above] and an oral report [max 5 minutes]
-

The written reports must make clear how and why you have taken the decisions you used. Oral reports must cover the most significant points only and refer to the written material.

SUBMISSION DUE: Construction plan report approval (part i) 19th August

Final submission part ii; Sept 9th, 2003 – 4:00pm

GROUP SIZE: Three (3) of own choice. Second written report to include mark distribution

MARKING SCHEDULE: 100 marks for the project allocated as follows;

- Construction plans [as per 1 above], 30 marks
- Oral report on construction plans, 20 marks
- A written report on construction, plan changes & recommendations [as per 3 & 4 above]. 30 marks
- Oral report on construction phase, 20 marks

For each report half of the marks will be for content – data, use of data, justification, application and use of data. The remaining half will be on presentation, clarity, level of detail, format and style.

LENGTH:

The written reports should be concise but sufficient for a director to view and understand without oral input.

The oral reports will be no more than 5 minutes long. These reports need to *summarise* the major points, decisions and reasoning. The draw charts and other written material can be used as visual aids may be used.

E. MCG Umpire – Contents of the student record file

Field	Type	Length	Start
Activity code	real	5:1	1
Filler	space	1	6
Activity description	string	28	7
Filler	Space	1	35
Calendar date	string	10	36
Filler	space	1	46
Actual time	string	8	47
Project day number	integer	4	55
Number of playing seconds	integer	7	59
Filler	space	1	66
Clay height	real	8:2	67
Rock height	real	8:2	75
Cumulative planned clay expenditure	real	12:2	83
Cumulative planned rock expenditure	real	12:2	95
Cumulative planned total expenditure	real	12:2	107
Cumulative planned clay income	real	12:2	119
Cumulative planned rock income	real	12:2	131
Cumulative planned total income	real	12:2	143
Cumulative actual clay expenditure	real	12:2	155
Cumulative actual rock expenditure	real	12:2	167
Cumulative actual total expenditure	real	12:2	179
Cumulative actual clay income	real	12:2	191
Cumulative actual rock income	real	12:2	203
Cumulative actual total income	real	12:2	215
Requested number of scrapers	integer	4	227
Actual number of scrapers	integer	4	231
Type of scrapers	integer	4	235
Requested number of lorries	integer	4	239
Actual number of lorries	integer	4	243
Type of lorries	integer	4	247
Requested number of excavators	integer	4	251
Actual number of excavators	integer	4	255
Type of excavators	integer	4	259
Requested number of rock compactors	integer	4	263

Actual number of rock compactors	integer	4	267
Type of rock compactors	integer	4	271
Requested number of clay compactors	integer	4	275
Actual number of clay compactors	integer	4	279
Type of clay compactors	integer	4	283
Requested number of lorry graders	integer	4	287
Actual number of lorry graders	integer	4	291
Type of lorry graders	integer	4	295
Requested number of scraper graders	integer	4	299
Actual number of scraper graders	integer	4	303
Type of scraper graders	integer	4	307
Lorry haul road gradient	real	8:2	311
Scraper haul road gradient	real	8:2	319
Number of wet weather graders	real	8:2	327
Blow up rainfall	real	8:2	335
Actual daily rainfall	real	8:2	343
Number of clay engineers	integer	3	351
Number of rock engineers	integer	3	354
Number of clay foremen	integer	3	357
Number of rock foremen	integer	3	360
Number of planners	integer	3	363
Number of secretaries	integer	3	366
Environment training	integer	5	369
Safety training	integer	5	374
Quality training	integer	5	379
Environment supervision	integer	5	384
Safety supervision	integer	5	389
Quality supervision	integer	5	394
The week number	integer	4	399
Number of plans made	integer	5	403
BVWD planned cumulative	real	12:2	408
BVWD actual cumulative	real	12:2	420
BVWD planned period	real	12:2	432
BVWD actual period	real	12:2	444
Current budget variance	real	12:2	456
Performance variance	real	12:2	468
Efficiency variance	real	12:2	480
Budget revision variance	real	12:2	492

Planned performance - period	real	8:2	504
Planned performance - cumulative	real	8:2	512
Actual performance - period	real	8:2	520
Actual performance - cumulative	real	8:2	528
Efficiency - period	real	8:2	536
Efficiency - cumulative	real	8:2	544
Planned balance	real	12:2	552
Actual balance	real	12:2	564
Overall score	real	8:2	576
Problem level 1 score	real	8:2	584
Problem level 2 score	real	8:2	592
Planned Clay Progress	real	8:2	600
Planned Rock Progress	real	8:2	608

Table 11.5-1 : Contents of the Umpire record file

F. ACPM module description / student handout

APPLIED CONSTRUCTION PROJECT MANAGEMENT
Module No.: H24MPM

Session: 2008 - 2009 **Semester: Spring**

Module Convener: Dr M J Mawdesley

INTRODUCTION AND FEEDBACK FROM LAST SESSION

This module is intended to fill the gap between Construction Management theory and practice in project planning, resource utilisation, project control, project risk management and financial planning and control. It has been designed in a format which requires a considerable amount of student centred learning and therefore a large commitment on the part of the student. Last session, 15 fourth year and 8 MSc students took the module. The undergraduates achieved an average mark of 69% with a standard deviation of 5%. MSc students achieved an average of 63% with a standard deviation of 8%. Nine students had marks over 70% and none had a mark below 50%. Students gave feedback through SEM forms and by commenting throughout the course. The comments were very supportive. Suggestions for changes in the method of operation were made and have been considered for this year. In particular, it has been decided to include presentations in the semester. Staff and students also identified areas for changes in the simulations and new versions have been produced for this year's module.

AIMS AND OBJECTIVES

The module aims to provide students with the opportunity to learn techniques for the management of construction projects and to practice their application in as realistic an environment as practical.

By the end of the module students should:

- appreciate the benefits of and difficulties in the application of project planning techniques top construction projects
- understand the importance of information for project control
- appreciate the effects of uncertainty and manage the consequent risks and opportunities
- understand how resources interact both amongst themselves and

with the environment

SUMMARY OF CONTENTS

Procurement options for construction; estimating and tendering for construction; control for construction projects; introduction to practical planning.

LEARNING AND TEACHING METHODS

The learning and teaching is student centred and is based around simulations of construction projects. The simulation(s) will be used to guide students to notes prepared by the academics involved in the module and to relevant web sites. It will also provide the students with the opportunities to practice the use of the techniques and to understand the differences between theory and practice.

PRACTICAL CLASSES

None

ASSESSMENT

<u>Written Examination (70%)</u>

Duration 1½ hrs

No. of questions on paper 4 (selected from the examination questions below)

No. of questions to be attempted 3

<u>Coursework report (30%)</u>

A written report as per instructions below

APPRAISAL

This will be by feedback from individuals directly or through the tutees of the lecturers or through the standard mechanisms available (see School of Civil Engineering Undergraduate Handbook).

TEACHING TIMETABLE

Date	Time	Format	Topic
Thur.29/01/09	11.00	Lecture	Introduction to module
	12.00	Lecture	Introduction to simulations
Thur. 05/02/09	11.00	Clinic	Consultation on module
Thur. 12/02/09	11.00	Clinic	Consultation on module

Thur. 19/02/09	11.00	Clinic	Consultation on module
Thur. 26/02/09	11.00	Clinic	Group Presentation exercise
Thur. 05/03/09	11.00	Clinic	Consultation on module
Thur. 12/03/09	11.00	Clinic	Consultation on module
Thur. 19/03/09	11.00	Clinic	Consultation on module
Thur. 23/04/09	11.00	Clinic	Consultation on module
Thur. 30/04/09	11.00	Clinic	Consultation on module
Thur. 07/05/09	11.00	Clinic	Focus Group Revision exercise
Thur. 14/05/09	11.00	Clinic (tba)	Focus group revision exercise

Note: All other periods for this module between the end of this timetable and the start of examinations are scheduled as revision classes.

COURSEWORK

Choose one of the projects that you have worked on in the simulation and, acting as project manager for the main contractor, write a report on it to the board of your company. Note that in order to be able to do this properly, you will have to have kept records of the performance of the project throughout its duration.

Submission Date: 20th Mar 09 Target Return Date: 23rd Apr 09

Maximum marks available 30% of module marks.

Marks will be available for both the content and the style of the report.

EXAMINATION QUESTIONS

The examination paper will consist of four questions taken from the 10 below. Candidates should attempt three.

1. Describe and discuss the difficulties which can be encountered when using variances to control the progress of a construction project

2. Discuss the effects on construction project planning and control of resources working in teams rather than individually

3. Discuss the difficulties of including uncertainties in project planning and what effects the uncertainties can have on the effectiveness of control mechanisms.

4. Discuss how risks can be managed on a construction project before the work is carried out and whether this management removes the sources of risk.

5. Discuss whether basic engineering understanding is required to produce realistic plans for a construction project.

6. Describe sources for the information which is required to properly manage a construction project. Discuss whether the internet is sufficient as a single source of information.

7. Describe how safety, quality and the environmental considerations might influence project planning and control and discuss how these might be balanced with financial aspects of a project.

8. Discuss the problems and benefits of attempts to micro-manage a construction project by an off-site manager

9. Compare and contrast different numerical and graphical techniques for the control of construction projects

10. Describe how project information can be transferred from one project to another to help with project planning and control. Discuss how practical it is to obtain useful information by analysing that which has been collected.

REFERENCES

In addition to any reference material contained within the games, students might find the following references useful:

Mawdesley, Askew, O'Reilly, Planning and Controlling Construction Projects, Longman, 1999

Hendrickson, Project Management for Construction, available on-line at http://www.ce.cmu.edu/pmbook/

Fellows, Langford, Newcombe, Urry, Construction Management in Practice, Blackwell Science, 2nd edition, 2002

Pilcher, Principles of Construction Management, McGraw Hill, 3rd edition

TRANSFER ONTO AND OFF THE MODULE

The simulations run as part of this module require setting up for each student. This causes significant work which has to be done before students have access to them. Students' demand for staff time is also usually high at the start of the module. For these reasons, transfer either onto or off this module will only be sanctioned up to the start of the class on 5th February 2009

PRESENTATIONS

In previous years, students suggested that they would have benefitted from giving a presentation part way through the first term. Students will therefore be asked to give a presentation on their progress on the projects in the class on 26th Feb 2009. The format of these presentations will be specified nearer the time.

G. ACM – Muck Game instructions

The following is an abridged version of the instructions for the Muck game provided to students. Detailed screenshots and instructions related directly to the game interface have been omitted due to space restrictions. The full set of instructions is included in the e-appendices.

INTRODUCTION

In order to appreciate the benefits and problems associated with the collection, analysis and use of productivity information it is necessary to gain experience in these areas. Unfortunately, it is usually very expensive to achieve this with real projects because of the costs and risks involved.

As a substitute for reality, a 'Dam Construction Game' has been developed in which participants can take on management roles and experiment without fear of incurring the losses that would be likely in practice.

This exercise is designed to enable the participants to develop skills that have been or will be covered in theory and to explore their limitations. It is designed to be as realistic as possible whilst remaining simple and quick to operate.

OBJECTIVES

The objectives of the game can vary depending on the emphasis laid on the various aspects by the game controller. This is very much like real life where engineers perceive the objectives of a project very differently. For example, some consider the main objective is to construct the project, some to make a profit and others to ensure the future of the company. The real objective if it were possible to define would be a combination of all of these and others.

In these terms, the objective of the game might be stated as

- To construct the dam
- To construct the dam within the specified time
- To construct the dam with the maximum profit
- To construct the dam with due regard to quality, safety and the environment
- To plan, monitor and control the construction of the dam.

These will be achieved using the techniques covered by reading or in lectures. In addition the following sub-objectives should be borne in mind since they would be of use in reality and can be achieved in the game by analysis of the information provided. Indeed, the progressive achievement of these will assist in the attainment of the major objective.

- To understand the benefits and difficulties in the application of theories described in reading or in lectures

- To compare the effectiveness of different planning and control techniques on specific types of project.

- To understand the importance of information for project control

- To understand the effects of uncertainty and manage the risks and opportunities involved in a construction project.

- To determine the reliability of the various types of plant used in the construction of the dam.

- To understand how resources interact both amongst themselves and with the project environment.

This will allow us to gain practice in the application of project management methods and thereby to:

- Determine the productivity of the various types of plant used on the site.

- Develop a set of information which can be used for planning and scheduling similar projects in future.

- Compare the productivity and reliability information with that provided by manufacturers to determine the viability of using manufacturer's information for different types of plant.

PROJECT SYSTEMS

As in real projects, in order to achieve the objectives in the game, it is important to set up the systems to plan, monitor and control the project right from the start.

The site will, by default, provide information whenever a 'decision period' ends. A 'decision period' is the amount of time for which you, as project manager, allow your construction plant to operate. It can range from 1 day to 20 days. This is similar to the reporting mechanisms which operate on site that are usually set up to operate monthly. The more frequently the reporting system operates, the more it will cost but *to some extent*, the better and more useful the information will be.

Each participant should determine the systems which they wish to operate and set up the requisite paperwork at the start. The following section indicates what can be achieved and should help in the development of systems.

You should remember that in real life it is impossible to obtain information retrospectively. If the information is not collected / recorded when it generated, it will, in general, be lost for ever. The simulation is like real life in this respect.

CONTROL SYSTEM COMPONENTS

Plan of Work

The plans of work will have to be developed before any work is allowed on the site. It should consist of both physical and financial information and as such will probably at a minimum consist of graphs of height of dam against time and money (income, expenditure and profit) against time.

In order to develop the financial plan, the income and expenditure will be required. The income is based on physical progress; the expenditure is based on the resources (plant, etc.) used.

Plant Performance

The initial information contains “manufacturers’” information on the plant performance and some information from a similar site operated by the company.

Since the output of the plant will be required for future planning and estimating, it is essential that a method is developed to enable the current value of the ‘productivity’ to be provided at any time. It would also be useful to be able to provide information on variability of output with time or any other significant variable.

Each individual player of the game can decide the way that 'productivity' is measured but the computer will report the same information to all participants. For example, it is possible to measure productivity for an individual type of plant (excavators say) or for a gang working in series (excavators and lorries).

Some factors, such as breakdowns, will affect the productivity and be beyond the control of the manager in this game. The extra information provided however can be very useful in the monitoring process.

Weather effects can be observed and sometimes be evaluated if the correct records are kept. The weather records might also be useful in explaining a deviation from plan if they can be shown to have been un-predictable.

Monitoring and Control

The monitoring and control should be in terms of physical, financial and resource factors and Head Office might ask for a report at any stage.

CURRENCY

All currency in this document is quoted in local dollars and the symbol $ is used. All payments to and from the project will be made in this currency. No exchange considerations should be made in this exercise.

PROJECT DESCRIPTION

INTRODUCTION

You have been appointed to run an earthmoving contract that your firm has just won. The contract is for the construction of an earth dam across the bed of a valley, the top of the dam being utilised for the path of a new motorway. The valley runs in a north-south direction, and the dam is thus to be constructed on an east-west line. The motorway, when complete, will run out of a cutting on the east side of the valley, across the dam, and into a larger cutting on the west side of the valley.

The dam is to be of rock, with a central clay core, and the rockfill is to be obtained from the excavation for the motorway cutting on the west side of the valley. The clay fill is to be obtained from a borrow pit in the bottom of the valley, about 1km, away in a southerly direction. The cross-sections of both the valley and the dam are trapezoidal in shape, relevant dimensions being shown in the appended drawings.

CONTRACT INFORMATION

In order to ensure that the required standards of compaction are maintained, it is specified in the contract conditions that

1. At no time shall the rate of heightening of the rockfill exceed 1.5m/week (0.3m/day).

2. At no time shall the rate of heightening of the clayfill exceed 1.5m/week (0.3m/day).

3. At no time shall the difference in height between the placed rock and clay exceed 1 metre.

4. The contract duration is 40 weeks from the starting date of 1.11. 2005

Payment is made on the following terms:

1.An initial payment of $40,000 to cover the cost of overheads throughout the 40 week contract period.

2.Payment of $30,000 for each completed metre height of clayfill and $25,000 for each completed metre height of rockfill. A 10% retention is held back on each of these quantities, until that quantity is completed to the finished level of the dam the remaining 90% being paid immediately.

3.Over-running of the contract period will incur a penalty cost of $10,000 per week violated.

PLANT PERFORMANCE AND SELECTION

The profitable management of this project is dependant upon the selection of the most effective plant for each task in the correct relative numbers. In order to produce rockfill we require excavators to dig and lorries to transport. Thus, in terms of plant production, the maximum rock output will be the smaller of the total excavator and total lorry capacities. In order to place the rockfill we require lorries to bring in the rock and rock compactors to compact it. Thus, the maximum rock intake will be the smaller of the capacities of these two plant types. In the case of the clayfill, the scrapers alone excavate and transport the clay, while the intake of clay into the dam is dependant upon the scraper capacity and the clay compacting capacity. The task of the project managers is thus to blend the numbers of the chosen plant types in order to achieve the desired outputs of rockfill and clayfill with the minimum waste of machine capacity.

Further items of plant that will be required are graders, to improve the haul roads of both the lorries and scrapers. It may also be desirable to hire wet weather graders, but the uses of graders will be explained in subsequent sections.

Within these 8 species (species: several types of plant any of which can be used for a given operation) of plant there are several vehicle types, with differing characteristics, as detailed in Table 1. The reliability of each plant type, shown as a percentage, gives an indication of the likelihood of this plant being available for work (i.e. not broken down). The penalty for a breakdown is loss of production and the machine is still being paid for. The output of moving plant is inclusive of return journeys made empty - thus a capacity of 500m^{3}km/day means that the item of plant can move 500m^3 of material 1km in 1 day. The output of graders is a measure of their relative efficiency compared with the constant yardstick of raising the production of moving plant by 5%.

There are two restrictions regarding the choice of plant, the first being that in order to rationalise spares, only one type of plant can be used for each operation. Secondly, due to the need for manoeuvrability within the west cutting excavation, no more than 5 excavators are allowed to be working at any one time. It is, of course, permissible to hire more than 5, in order to combat breakdowns.

HAUL ROAD GRADIENTS

One of the factors governing the actual volumes of rock and clay production is the state of the haul roads used by the lorries and scrapers. The shallower the gradients of the haul roads, the longer they will be, but the plant will be better able to ascend the gradients in wet weather. It is recommended that the gradients selected for the haul roads should not be greater than 0.15 nor less than 0.05.

EFFECTS OF RAIN

The dam is being constructed in an area of high rainfall, and as a guide a table of average rainfall over the last 50 years is included in Table 2. The effect of rainfall is to speed the deterioration of haul roads. This deterioration can be combated by the employment of lorry haul graders and scraper haul graders, to improve the conditions of their respective haul roads. As stated earlier, it is expected that a grader should increase the production of moving plant by 5%, though it is not known at what rate production falls in this area due to the effects of rain. It would not be economical however, to employ the number of graders which would be required to combat the heaviest rainfall, so a "blow up" level of rainfall must be set, at which all work will be stopped. If work were continued through the heaviest rainfall, the condition of the haul roads would perhaps fall to the point where the moving plant could not even climb the gradients. When the rain stopped, it would take further time before production could rise as the graders would have a considerable task in remaking the haul roads.

In a similar way, if the weather is very dry, the roads may become very dusty causing the equipment to produce clouds of dust which would adversely affect the neighbours to the project. This can be combated by the use of 'graders' since these represent water bowsers, sprayers and the costs of any additive to this water.

There is one further aid that may be called in when required. A local plant hire firm is prepared to hire graders on a week-to-week basis, without hire/fire charges. These wet weather graders are called in when the production begins to fall as the road deteriorates through rain.

It is thus necessary to specify the blow up rainfall, in millimetres/month, and the number of wet weather graders to be used for each millimetre/month by which the rainfall exceeds the level at which the rain starts to reduce plant production. Since there is no documented evidence of the susceptibility of plant to rainfall in this area, the most suitable balance of graders and blow up rainfall must be deduced as the contract proceeds. It would, of course, be expected that rubber tyred plant is more susceptible to rain than tracked plant, though it will also be faster in dry conditions.

RUNNING COSTS

From the contract starting date until completion of the dam overhead costs will be incurred at the rate of $1000/week. In addition to this will be the plant hire costs, and the costs of hire/fire involved in bringing the plant to and from the site. Should overtime be worked on any species of plant (gaining 7 days production on that species of plant in place of 5), the overtime will be charged at time and a half.

Engineers and foremen are required to supervise the work and the amount of money spent on their training in a particular topic will affect their efficiency in that area of work.

You will also be able to increase performance on a particular task (monitoring quality, safety and environmental impact) by spending money on supervision of that task.

Finally, should the project's net balance be in the red, interest will be charged at 5% per month.

DECISIONS

As project manager, you will have to make decisions on, amongst other things, what equipment you want on site, for how long, what gradient you want the haul roads to be, at what level of rainfall you wish work to stop (blow up rainfall) and what supervision you require.

Average annual rainfall - 1289.3 millimetres

MONTH	MEAN (Millimetres)	ST. DEV. (Millimetres)
January	142.75	32.00
February	107.95	25.65
March	78.23	24.89
April	76.45	19.56
May	75.69	11.94
June	72.90	7.87
July	89.15	7.62
August	108.2	14.22
September	118.11	29.72
October	146.81	37.59
November	145.8	38.35
December	127.25	28.96

TABLE 2 - Monthly rainfall. (Average of last 50 years)

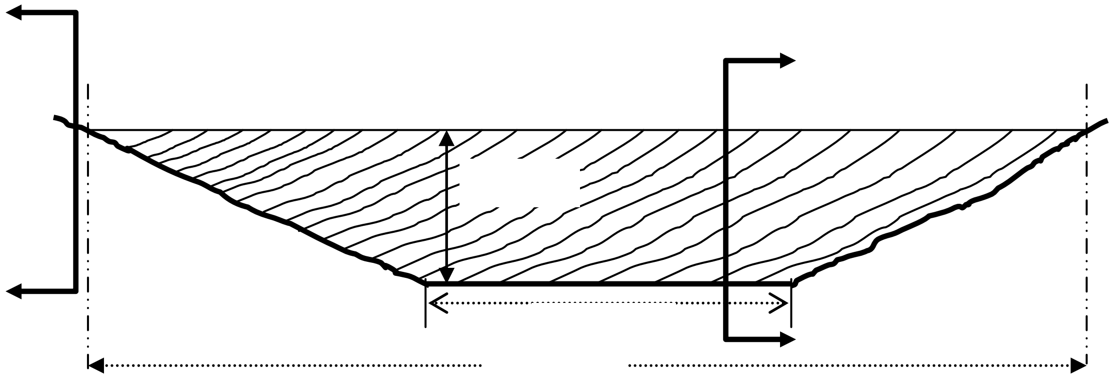
Table 1. Plant Performance

(Local Currency)

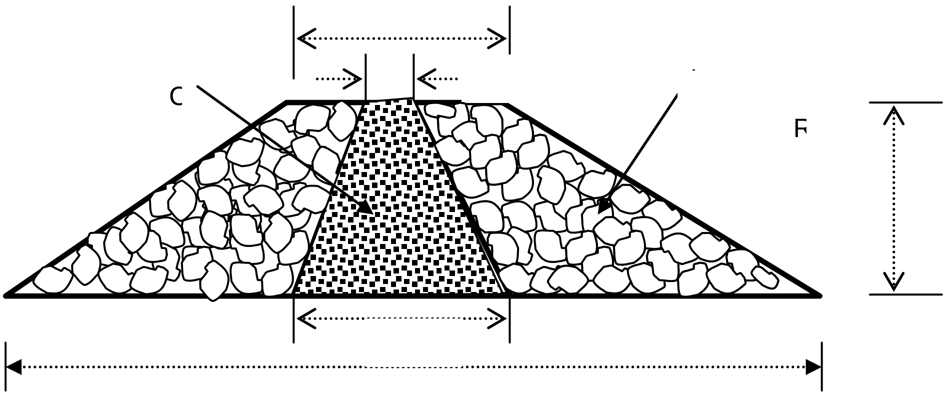
SPECIES	NAME	TYPE NO.	RELIABILITY	OUTPUT	HIRE RATE 5 days	HIRE//FIRE RATE
SCRAPERS	CAT 657B (TWIN)	1	91%	1780 m^3/day	$2800	$280
	GENERAL MOTORS TS-14 (TWIN)	2	92%	900 m^3/day	$1425	$142
	CAT 631 C (SINGLE)	3	93%	1190 m^3/day	$1700	$170
	GENERAL MOTORS TS 24 (TWIN)	4	91%	1340 m^3/day	$2100	$210
	CAT D8 + SCRAPER BOX	5	96%	530 m^3/day	$1240	$124
LORRIES	Aveling Barford SN 35	6	90%	550 m^3/day	$775	$ 77
	Aveling- Barford SL 300	7	92%	340 m^3/day	$550	$ 55
	General Motors TEREX R 45	8	89%	570 m^3/day	$850	$ 85
	Foden 4 DL6/24	9	90%	360 m^3/day	$550	$55
EXCAVATORS	71 R-B	10	93%	650 m^3/day	$1500	$150
	110 R- B	11	92%	1460 m^3/day	$2500	$250
	150 R-B	12	90%	1790 m^3/day	$3500	$350
ROCK COMPACTORS	CAT D8 + Vibrator Roller	13	95%	4700 m^3/day	$1240	$124
	CAT 815	14	94%	4000 m^3/day	$1000	$100
CLAY COMPACTORS	CAT D8 + Vibrator Roller	15	95%	3000 m^3/day	$1240	$124
	CAT 815	16	94%	6100 m^3/day	$1000	$100
LORRY HAUL ROAD GRADERS	CAT D8	17	96%	0.9*	$1125	$112
	Aveling -Austin 99H	18	94%	1.0*	$ 750	$ 75
SCRAPER HAUL ROAD GRADERS	CAT D8	19	96%	0.8*	$1125	$112
	Aveling-Austin 99H	20	94%	0.8*	$ 750	$ 75
WET WEATHER GRADERS	Aveling-Austin SUPER 500	N/A	96%	1.0*	$1200	N/A

* Grader efficiency relative to the raising of moving plant production by 5%.

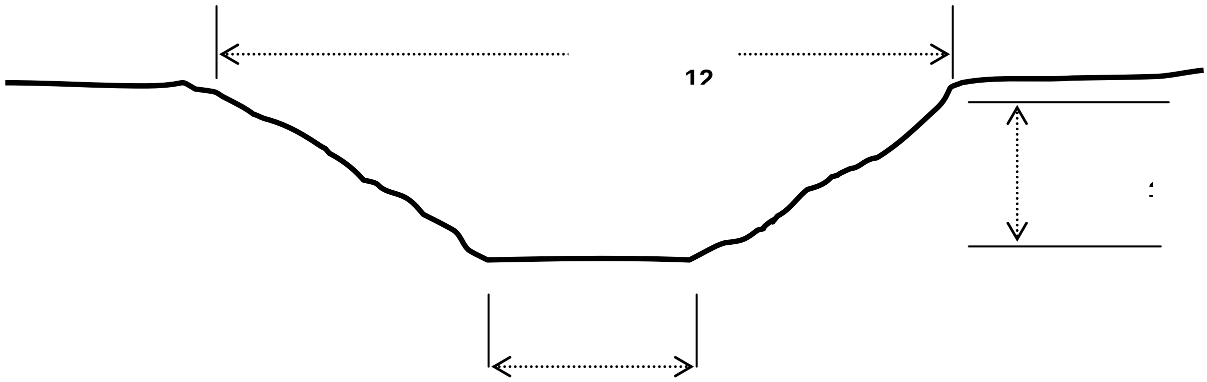
SKETCHES OF DAM



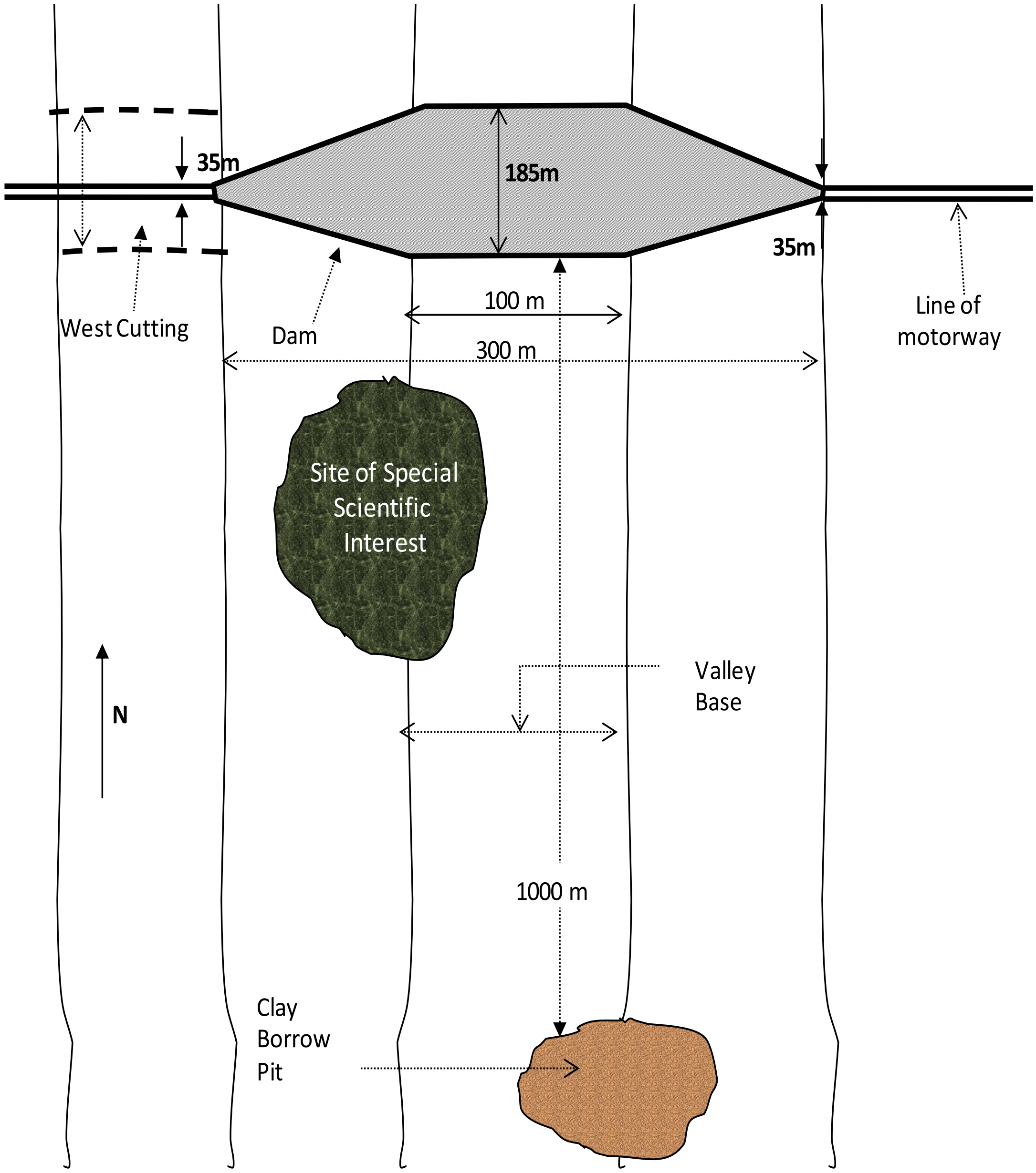
Dam- Side Elevation



Dam- Cross-Section A-A



Dam- Cross-section B-B



H. *ACPM Module Evaluation Form*

Module Evaluation
Applied Construction Management
H24MPM
2006-2007

The University of Nottingham

This questionnaire is part of a continuing effort by the University to improve modules and teaching and to promote learning. The questionnaire is entirely anonymous.

Please answer all the questions that apply to you by ticking the category which best reflects your view. Overleaf there is the opportunity for you to provide feedback in your own words.

Course — MSc ☐ — MEng ☐

	N/A	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
A good module outline was provided	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The module was well organised	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
Playing the simulation games was an effective method of learning	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The design of the game interface was appropriate	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The requirements of the coursework assignment were clear	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The coursework should not be restricted to reporting on a single play-through of the game	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
Module assessment should include my performance at the games	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The simulation games provided a realistic depiction of managing a large infrastructure project	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The module has helped me to understand project management	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The module has developed my interest in the subject	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
This module relates to others I have studied	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
Greater difference between the 2 games would benefit the module	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The method of teaching was more entertaining than lectures	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6

	N/A	Much too great	Bit too great	Yes	Bit too low	Much too low
The work-load was just right	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The number of games available	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The complexity/difficulty of the games	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
The number of attempts at the games was appropriate	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6

	N/A	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The module would benefit from the inclusion of lectures on…						
Project Planning	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
Financial Management	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
Plant performance and productivity	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
Dam and canal construction methods	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6

Open-ended comments

What did you like about this module?

How could this module be improved?

Please use this space for any further comments you would like to make about the module.

Thank you for taking the time to complete this questionnaire

I. Appendix ACPM Statistical data for years 2, 3 and 4 of operation

Year 2 – Academic Year 2006/2007

KPI	Statistic	All players	>5% Progress completed	Completed Games only
Time Spent	Mean	337.73	374.87	423.47
	St Dev	355.65	359.96	419.08
	Min	0.13	3.70	31.77
	Max	2882.40	2882.40	2882.40
Project Duration	Mean	137.93	156.46	155.77
	St Dev	76.86	62.07	44.13
	Min	0.00	11.00	107.00
	Max	251.00	251.00	251.00
Project Spend	Mean	2,517,074	2,857,169	3,280,982
	St Dev	3,735,025	3,859,164	4,719,983
	Min	0	151,781	1,305,886
	Max	30,323,691	30,323,691	30,323,691
Number of Plans made	Mean	3.91	4.39	4.17
	St Dev	3.18	3.07	2.96
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	-1,229,196	-1,449,217	-1,594,698
	St Dev	3,651,748	3,790,305	4,718,959
	Min	-28,633,691	-28,633,691	-28,633,691
	Max	384,114	384,114	384,114
Daily Spend	Mean	14,973	16,718	18,432
	St Dev	14,414	14,420	17,814
	Min	0	8,762	9,106
	Max	120,812	120,812	120,812

Table 11.5-2: Statistical results from use of Muck Game in academic year 2006/2007

KPI	Statistic	Run 1st	2nd	3rd	4th	5th
Number of Players	Started	73	62	42	29	2
	Finished	32	32	32	17	2
	%finish	43.8%	51.6%	76.2%	58.6%	100
Time Spent	Mean	370.83	304.85	400.70	189.79	971.33
	St Dev.	326.01	295.74	467.46	180.61	791.47
	Min	0.13	0.73	0.25	0.20	179.87
	Max	1874.42	1935.15	2882.40	720.78	1762.80
Project duration	Mean	148.18	143.23	141.71	95.14	140.50
	St Dev	87.60	77.26	54.04	62.23	15.50
	Min	0.00	0.00	0.00	0.00	125.00
	Max	251.00	251.00	233.00	251.00	156.00
Project Spend	Mean	2,720,413	3,162,154	2,124,811	1,247,331	1,746,501
	St Dev	3,762,260	5.195,148	1,498,400	776,720	122,480
	Min	0	0	0	0	1,624,021
	Max	30,323,691	28,197,628	9.313.812	3,028,204	1,718,182
Number of Plans made	Mean	5.08	4.03	2.88	2.38	1
	St Dev	3.56	2.87	2.57	2.37	0
	Min	0	0	0	0	1
	Max	10	10	10	9	1
Overall Profit	Mean	-1,626,714	-1,908,042	-632,845	-85,655	-105,212
	St Dev	3,547,292	5,041,877	1,393,918	350,489	171,270
	Min	-28,633,691	-26,507,628	-7,623,812	-1,455,204	-276,482
	Max	195,022	251,137	384,114	333,219	66,058
Daily Spend	Mean	14,411	17,958	13,653	12,090	12,486
	St Dev	14,672	19,720	5,954	5,875	506
	Min	0	0	0	0	11,981
	Max	120,812	115,564	39,973	24,707	12,992

Table 11.5-3 : Key performance variables for the Muck game by run number from year 2 of operation (academic year 2006-2007)

KPI	Statistic	All players	>5% Progress completed	Completed Games only
Time Spent	Mean	248.69	340.40	341.09
	SD.	336.10	369.68	234.33
	Min	0.12	47.13	47.13
	Max	3164.70	3164.70	1127.40
Project Duration	Mean	259.65	383.17	443.09
	SD	216.91	149.45	85.55
	Min	0	20	257
	Max	745	745	745
Project Spend	Mean	5,102,785	7,532,857	9,043,716
	SD	5,315,870	4,846,937	4,460,971
	Min	0	342,427	4,514,868
	Max	26,339,401	26,339,401	26,339,401
Number of Plans made	Mean	2.17	3.06	2.90
	SD	2.49	2.44	2.28
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	-862,891	-1,280,582	-1,243,514
	SD	3,292,119	3,933,954	4,461,116
	Min	-18,539.401	-18,539,401	-18,539,401
	Max	3,288,320	3,288,320	3,288,320
Daily Spend	Mean	13,115	18,763	19,949
	SD	10,056	6,422	6,618
	Min	0	9,393	12,078
	Max	45,176	45,176	45,176

Table 11.5-4 : Statistical results from use of Canal Game in academic year 2006/2007

KPI	Statistic	Run 1st	2nd	3rd	4th	5th
Number of Players	Started	68	35	21	7	2
	Finished	30	19	14	3	1
	%Finish	44.12	54.29	66.67	42.86	50.00
Time Spent	Mean	245.39	225.28	298.52	275.51	153.37
	SD.	394.63	236.60	262.92	354.72	152.62
	Min	0.13	0.20	0.12	47.13	0.75
	Max	3164.70	998.93	864.55	1127,40	305.98
Project Duration	Mean	251.12	266.77	297.52	211.29	196.50
	SD	228.65	214.17	187.07	178.80	196.50
	Min	0.00	0.00	0.00	0.00	0.00
	Max	745.00	547.00	520.00	427.00	393.00
Project Spend	Mean	5,555,375	4,859,365	4,655,570	3,647,685	3,763,155
	SD	6,374,090	4,304,462	3,120,972	3,286,869	3,763,155
	Min	0	0	0	0	0
	Max	26,339,401	14,341,134	9,460,264	8,752,832	7,526,310
Number of Plans made	Mean	2.35	1.91	1.90	2.86	1,00
	SD	2.83	2.10	2.02	2.02	1.00
	Min	0	0	0	0	0
	Max	10	10	9	6	2
Overall Profit	Mean	-1,759,406	-302,925	679,952	132,119	136,845
	SD	4.083,281	1,971,494	1,379,262	1,008,051	136,845
	Min	-18,539,401	-6,541,134	-1,660,264	-1,396,995	0
	Max	2,424,101	2,886,344	3,288,320	1,515,736	273,690
Daily Spend	Mean	13,761	12,117	12,409	14,961	9,575
	SD	11,486	9,021	6,605	7,629	9,575
	Min	0	0	0	0	0
	Max	45,176	28,120	21,551	24,452	19,151

Table 11.5-5: Key performance variables for the Canal game by run number from year 2 of operation (academic year 2006-2007)

Year 3 – Academic Year 2007/2008

KPI	Statistic	All players	>5% Progress Completed	Completed Games only
Time Spent	Mean	212.10	223,33	258.73
	SD.	194.81	196.36	214.76
	Min	0.15	8.63	18,50
	Max	991.25	991.25	991.25
Project Duration	Mean	164.50	183.89	205.83
	SD	75.52	54.29	24.93
	Min	0	31	108
	Max	250	250	243
Project Spend	Mean	2,734,130	3,062,244	3,788,332
	SD	2,446,303	2,394,475	2,636,574
	Min	0	371,982	1,744,609
	Max	13,786,159	13,786,159	13,786,159
Number of Plans made	Mean	3.06	3.39	3.75
	SD	2.30	2.23	2.30
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	-1,447,410	-1,621,270	-2,088,707
	SD	2,188,179	2,258,040	2,645,272
	Min	-12,096,159	-12,095,159	-12,095,159
	Max	108,891	108,891	108,891
Daily Spend	Mean	14,765	16,035	17,925
	SD	9,676	9,330	10,869
	Min	0	7,093	8,988
	Max	59,940	59,940	59,940

Table 11.5-6: Statistical results from use of Muck Game in academic year 2007/2008

KPI	Statistic	Run 1st	2nd	3rd	4th	5th
Number of Players	Started	18	15	15	10	3
	Finished	8	11	11	6	0
	%Finish	44.44	73.33	73.33	60.00	0
Time Spent	Mean	268.80	206.45	247.51	137.81	108.36
	SD.	120.68	141.94	305.90	139.29	89.89
	Min	0.15	21.02	18.50	8.63	10.42
	Max	529.35	511.63	991.25	461.98	227.52
Project Duration	Mean	186.50	184.07	170	143.20	52.33
	SD	77.56	56.97	61.97	75.23	70.50
	Min	0	0	0	5	0
	Max	250	242	239	206	152
Project Spend	Mean	3,949,485	3,349,223	2,151,925	1,659,204	535,928
	SD	2,879,518	3,018,794	1,020,,791	841,538	724,307
	Min	0	0	0	61,457	0
	Max	11,852,468	13,786,159	4,229,519	2,953,737	1,559,879
Number of Plans made	Mean	3.89	3.07	3.13	2.80	0.67
	SD	2.21	2.46	1.54	2.86	0.47
	Min	0	0	0	1	0
	Max	8	10	5	10	1
Overall Profit	Mean	-2,634,457	-1,957,289	-727,492	-375,103	-119,253
	SD	2,572,133	2,824,408	729,198	407,232	185,602
	Min	-10,162,468	-12,096,159	-2,539,519	-1,380,737	-381,379
	Max	0	0	108,891	10,053	23,621
Daily Spend	Mean	19,423	16,233	11,786	12,196	6,614
	SD	11,338	12,671	4,353	2,262	4,685
	Min	0	0	0	9,289	0
	Max	48,776	59,940	17,697	16,378	10,262

Table 11.5-7: Key performance variables for the Muck game by run number from year 3 of operation (academic year 2007/2008)

KPI	Statistic	All players	>5% Progress Complete	Completed games only
Time Spent	Mean	300.46	342.65	335.64
	SD.	247.50	241.28	220.89
	Min	1.52	31.10	31.10
	Max	1019.90	1019,90	979.45
Project Duration	Mean	318.60	372.85	376.94
	SD	141.99	58.49	49.73
	Min	0	156	256
	Max	472	472	472
Project Spend	Mean	5,025,442	6,930,072	7,081,824
	SD	3,874.948	3,264,393	3,377,716
	Min	0	2,494,544	4,387,910
	Max	22,463,239	22,463,239	22,463,239
Number of Plans made	Mean	1.96	2.27	2.22
	SD	1.93	1.91	1.97
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	482,963	567,572	718,744
	SD	2,963.401	3,198,578	3,378,025
	Min	-14,663,239	-14,663,239	-14,663,239
	Max	3,415,376	3,415,376	3,415,376
Daily Spend	Mean	16,727	18,411	18,625
	SD	10,158	7,287	7,699
	Min	0	12,128	12,128
	Max	56,018	56,018	56,018

Table 11.5-8: Statistical results from use of Canal Game in academic year 2007/2008

KPI	Statistic	Run 1st	2nd	3rd	4th	5th
Number of Players	Started	19	15	9	4	1
	Finished	12	13	7	4	0
	%Finish	63.16	86.67	77.78	100	0
Time Spent	Mean	346.71	246.21	308.88	336.43	15.67
	SD.	291.98	145.47	186.07	360.44	0
	Min	1.52	9.30	36.82	31.10	15.67
	Max	1019,90	496.58	567.62	935	15.67
Project Duration	Mean	304.37	327.27	330.44	406.75	0
	SD	148.47	134.60	120.76	41.97	0
	Min	0	0	0	367	0
	Max	462	461	450	472	0
Project Spend	Mean	6,407,749	5,373,888	5,508,009	8,123,391	0
	SD	4,867,260	2,345,470	2,641,994	3,882,357	0
	Min	0	0	0	5,141,611	0
	Max	22,463,239	8,418,150	10,525,676	14,796,509	0
Number of Plans made	Mean	2.58	1.53	2.00	1	0
	SD	2.18	1.31	2.21	0	0
	Min	0	0	0	1	0
	Max	10	6	7	1	0
Overall Profit	Mean	-379,569	1,393,395	1,198,334	-322,972	0
	SD	3,771,007	1,278,178	1.901,029	3,882,574	0
	Min	-14,663,239	-618,150	-2,725,676	-6,996,509	0
	Max	3,043,039	3,415,376	3,385,496	2,658,389	0
Daily Spend	Mean	17,507	17,427	14,607	19,355	0
	SD	11,936	9,455	6,128	7,063	0
	Min	0	0	0	13,784	0
	Max	56,018	48,040	23,390	31,349	0

Table 11.5-9: Key performance variables for the Canal game by run number from year 3 of operation (academic year 2007/2008)

Year 4 – Academic Year 2008/2009

KPI	Statistic	All players	>5% Progress completed	Completed games only
Time Spent	Mean	242.76	265.91	275.67
	SD.	186.55	179.52	178.90
	Min	0.07	25.90	46.33
	Max	831.62	831.62	831.62
Project Duration	Mean	156.68	172.01	178.09
	SD	75.45	60.28	42.81
	Min	0	19	109
	Max	251	251	251
Project Spend	Mean	2,967,326	3,258,994	3,693,100
	SD	3,775,887	3,836,014	4,301,960
	Min	0	334.579	1,435,688
	Max	28,192,129	28.192,129	28,192,129
Number of Plans made	Mean	3.51	3.85	3.83
	SD	2.96	2.89	2.87
	Min	0	1	1
	Max	10	10	10
Overall Profit	Mean	-1,633,768	-1,794,902	-2.005,308
	SD	3,618,122	3,753,949	4,301,162
	Min	-26,502,129	-26,502,129	-26,502,129
	Max	254,312	254,312	254,312
Daily Spend	Mean	16,131	17,611	18,963
	SD	14,552	14,405	16,363
	Min	0	8,797	9,979
	Max	112,319	112,319	112,319

Table 11.5-10: Statistical results from use of Muck Game in academic year 2008/2009

KPI	Statistic	Run 1st	2nd	3rd	4th
Number of Players	Started	23	22	22	11
	Finished	14	16	17	6
	%Finish	60.87	72.73	77.27	54.55
Time Spent	Mean	312.89	265.94	189.63	156.01
	SD.	207.35	190.40	138.04	175.11
	Min	0.12	0.82	0.53	0.07
	Max	825.93	831.62	512.07	519.50
Project Duration	Mean	184.74	175.14	135.64	103.18
	SD	70.48	61.64	67.62	89.21
	Min	0	0	0	0
	Max	251	250	250	244
Project Spend	Mean	4,908,610	2,504,685	2,033,923	1,700,363
	SD	6,273,853	1,202,725	1,405,420	2,001,856
	Min	0	0	0	0
	Max	28,192,129	6,270,743	6,062,671	7,221,711
Number of Plans made	Mean	4.65	3.64	2.91	2.09
	SD	3.23	2.92	2.52	2.57
	Min	0	0	0	0
	Max	10	10	10	8
Overall Profit	Mean	-3,558,828	-1,077,367	-622,560	-743,863
	SD	6,089,355	1,060,878	1,231,448	1,554,598
	Min	-26,502,129	-4,580,743	-4,372,671	-5,531,711
	Max	187,891	53,493	254,312	25,590
Daily Spend	Mean	22,963	13,598	13,875	11,428
	SD	24,379	4,748	5,201	8,692
	Min	0	0	0	0
	Max	112,319	27,029	25,052	29,597

Table 11.5-11: Key performance variables for the Muck game by run number from year 4 of operation (academic year 2008/2009)

KPI	Statistic	All players	>5% progress completed	Completed games only
Time Spent	Mean	172.43	396.13	354.04
	SD.	261.99	302.21	282.98
	Min	0.08	21.43	21.43
	Max	951.15	951.15	951.15
Project Duration	Mean	126.08	324.21	342.36
	SD	163.34	66.08	62.71
	Min	0	236	250
	Max	461	461	461
Project Spend	Mean	2,305,765	5,929,110	6,398,322
	SD	3,124,522	1,902,817	1,860,151
	Min	0	3,463,607	4,552,232
	Max	11,734,498	11,734,498	11,734,498
Number of Plans made	Mean	0.78	1.64	1.64
	SD	0.89	0.72	0.77
	Min	0	1	1
	Max	3	3	3
Overall Profit	Mean	235,040	568,675	1,401,678
	SD	1,464,381	2,308,527	1,860,151
	Min	-3,934,498	-3,934,498	-3,934,498
	Max	3,247,768	3,247,768	3,247,768
Daily Spend	Mean	7,150	18,386	18,874
	SD	9,350	4,271	4,270
	Min	0	12,370	12,669
	Max	27,676	27,676	27,676

Table 11.5-12: Statistical results from use of Canal Game in academic year 2008/2009

KPI	Statistic	Run 1st	2nd	3rd	4th
Number of Players	Started	19	9	6	2
	Finished	8	3	0	0
	%Finish	42.11	33.33	0	0
Time Spent	Mean	207.11	220.75	47.38	0.74
	SD.	282.97	282.41	76.59	0.64
	Min	0.45	0.12	0.08	0.1
	Max	951.15	664.03	213.88	1.38
Project Duration	Mean	182.26	119.56	0	0
	SD	161.13	176.26	0	0
	Min	0	0	0	0
	Max	424	461	0	0
Project Spend	Mean	3,554,554	1,719,002	0	0
	SD	3,419,490	2,450,140	0	0
	Min	0	0	0	0
	Max	11,734,498	5,840,598	0	0
Number of Plans made	Mean	0.89	1.00	0.33	0
	SD	0.85	1.05	0.47	0
	Min	0	0	0	0
	Max	3	3	1	0
Overall Profit	Mean	6,972	903,220	33,333.33	0
	SD	1,737,379	1,268,124	47,140	0
	Min	-3,934,498	0	0	0
	Max	2,553,314	3,247,768	100000	0
Daily Spend	Mean	11,190	4,977	0	0
	SD	10,061	7,170	0	0
	Min	0	0	0	0
	Max	27,676	18,209	0	0

Table 11.5-13: Key performance variables for the Canal game by run number from year 4 of operation (academic year 2008/2009)

J. ACPM Additional charts and graphs for students used as case studies

The figures shown in this appendix are examples of ones used during the operation of the games to monitor the performance of the students. The students selected here are the ones that are used as examples in chapters 8 and 10.

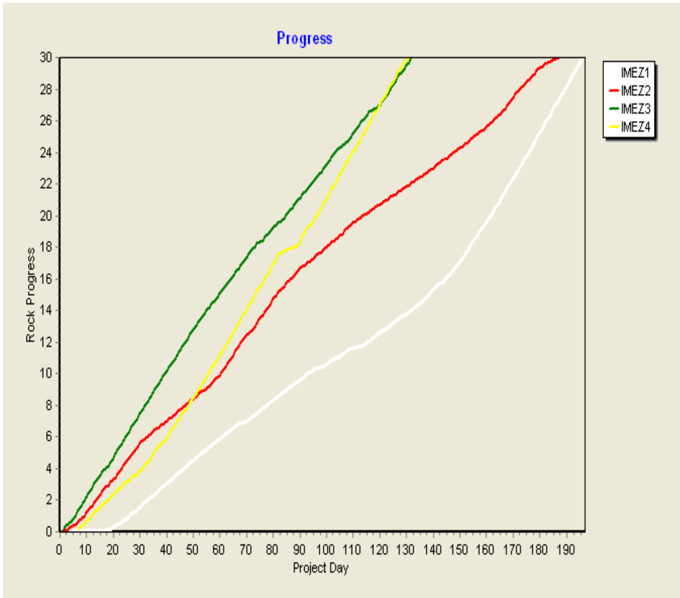


Figure 11.5-7: Student progress against time for student #6

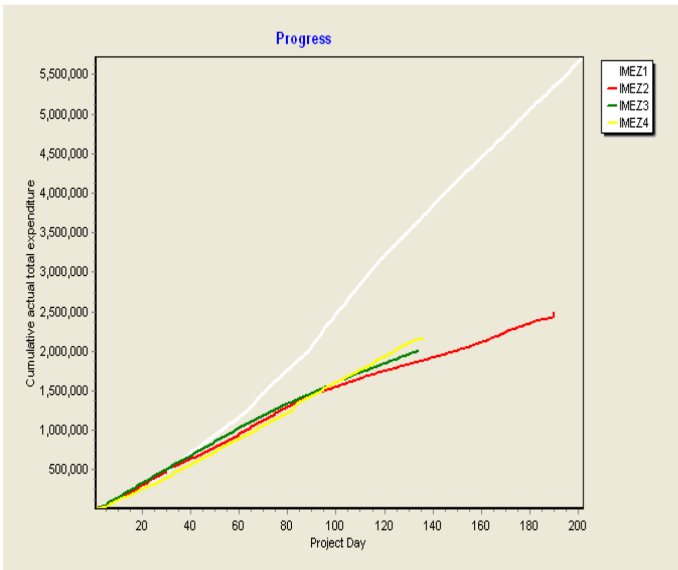


Figure 11.5-8: Project Expenditure against time for student #6

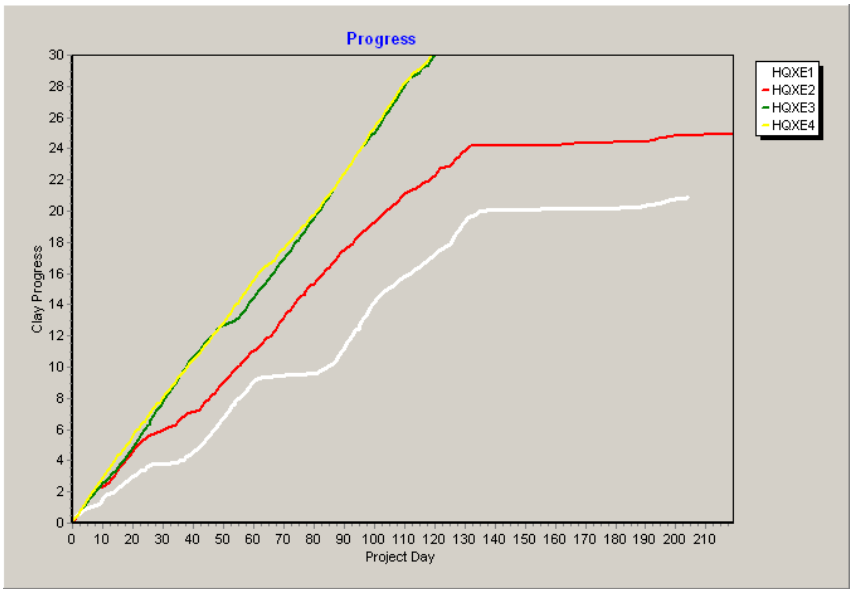


Figure 11.5-9: Clay Progress vs. Project Day for all runs of the game for student #7

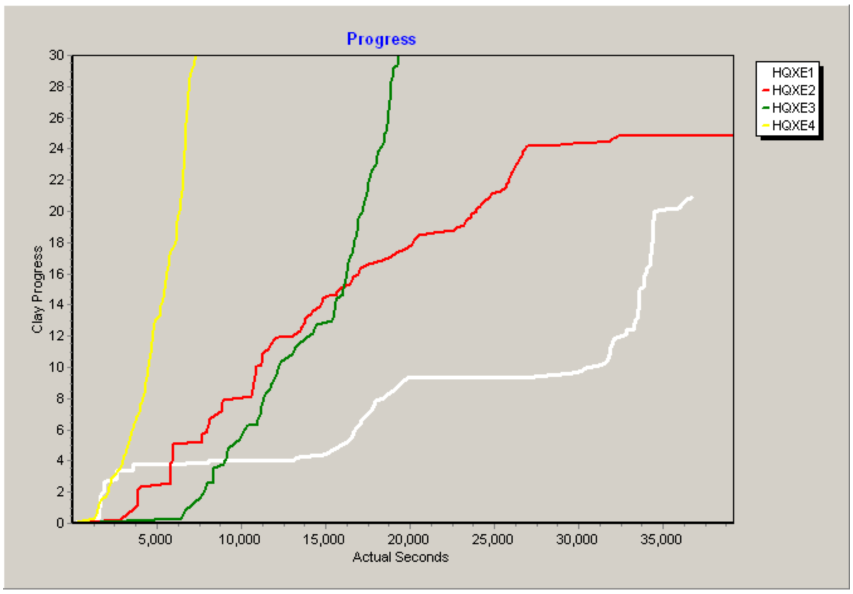


Figure 11.5-10: Clay Progress vs. Actual Seconds for all runs of the game for student #7

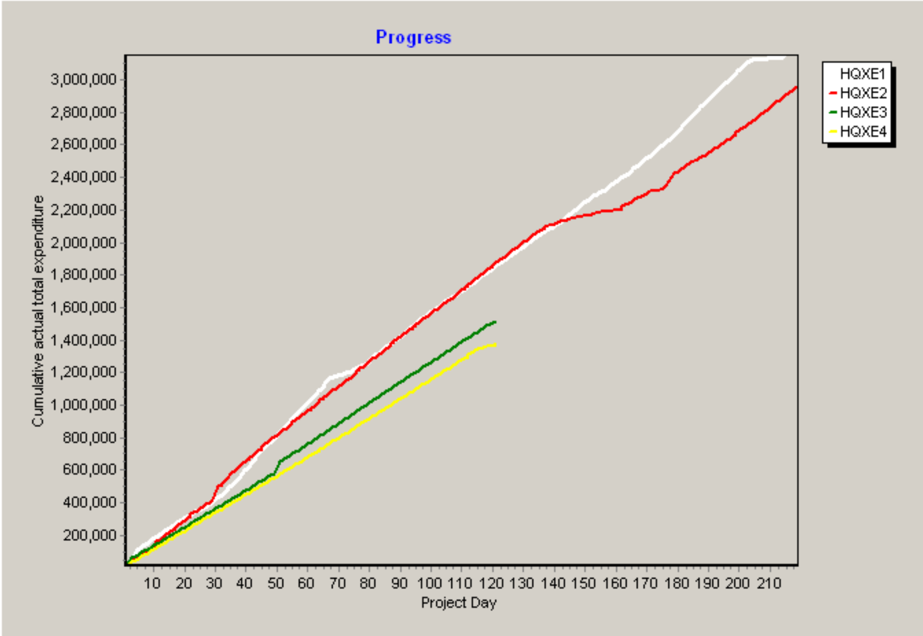


Figure 11.5-11: Cumulative expenditure against project day for all runs of the game for student #7

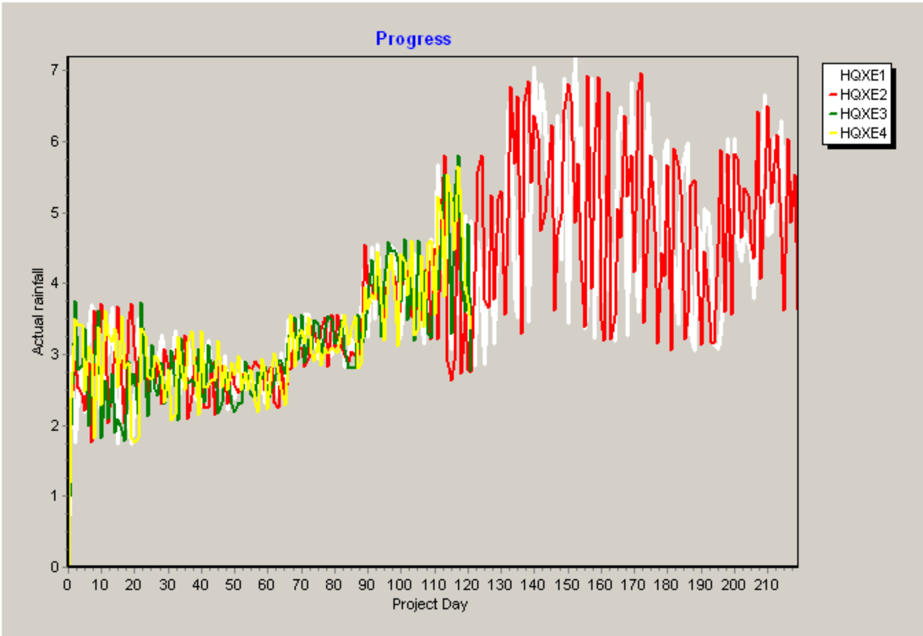


Figure 11.5-12: Actual rainfall chart for all runs of the game for student #7

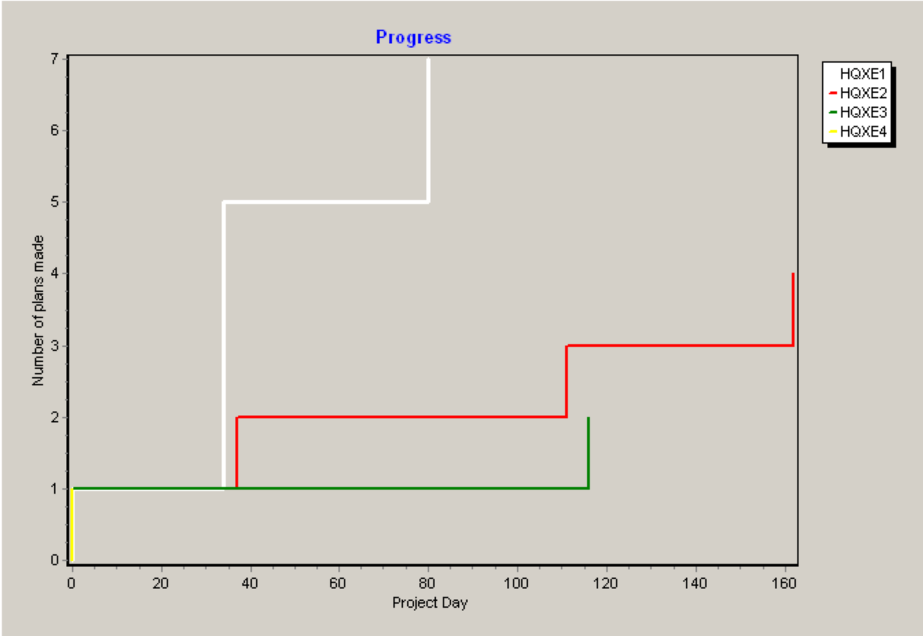


Figure 11.5-13: Number of plans made for all runs of the game for student #7

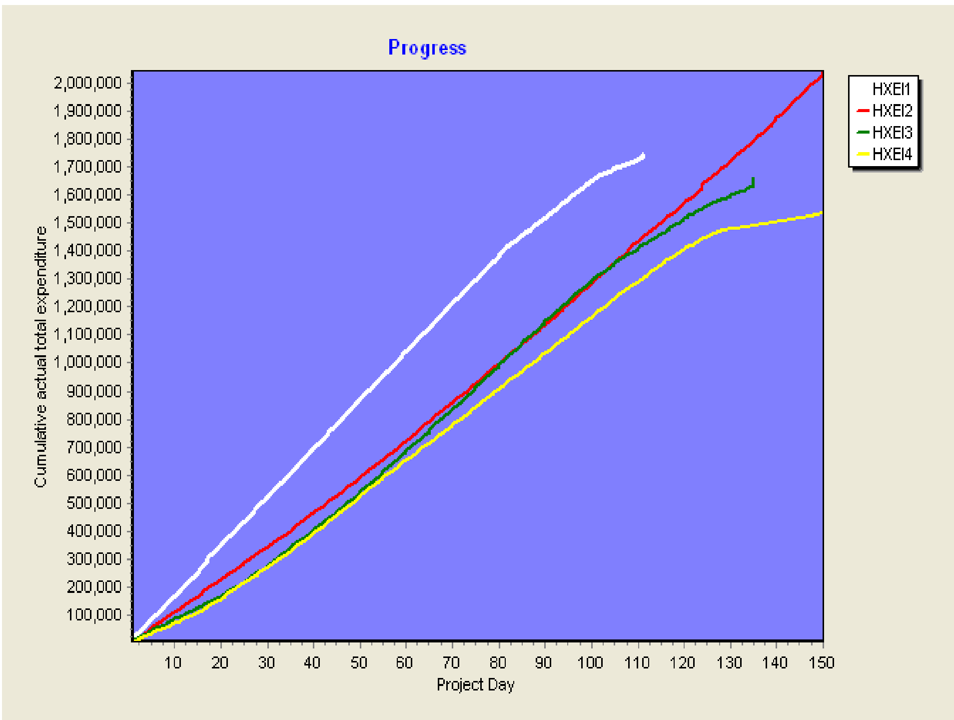


Figure 11.5-14: Actual spend for all four runs of the Muck Game for student #7

Figure 11.5-15: Rock progress for all 4 runs of the Muck game for student #7

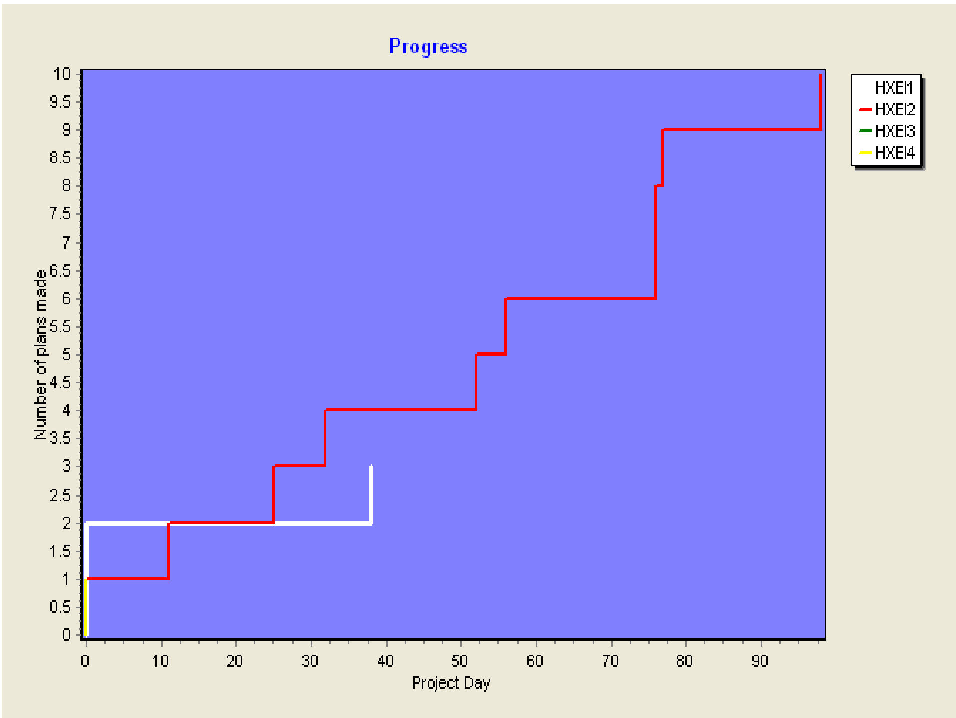


Figure 11.5-16: Number of plans made for all 4 runs of the Muck game for student #7

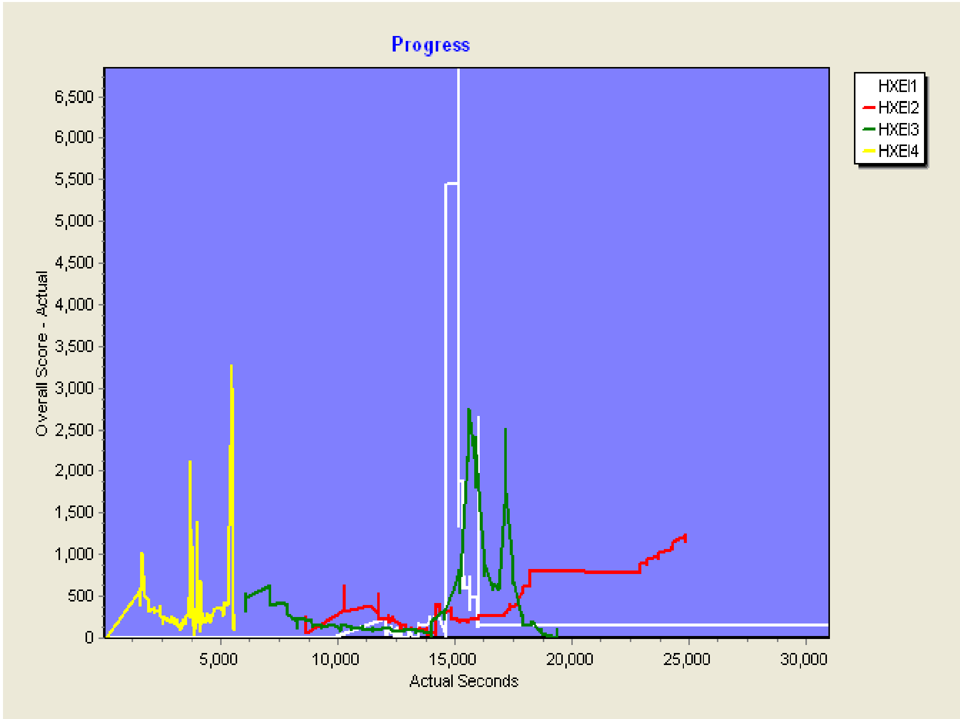


Figure 11.5-17: Summary Measure for all 4 runs of the Muck game for student #7

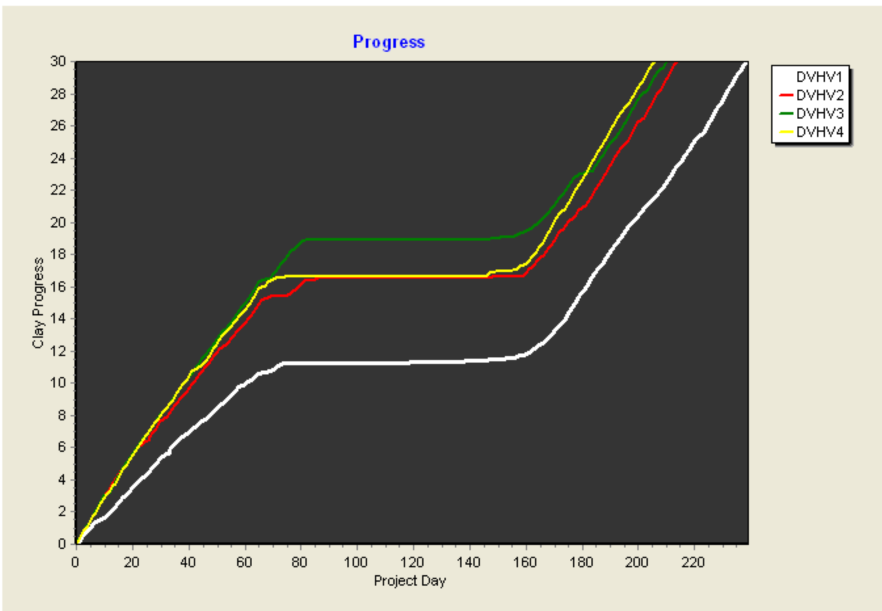


Figure 11.5-18: Typical s-type progression curve to allow for heavy rainfall in midpoint of project for all 4 runs of the Muck game for student #10

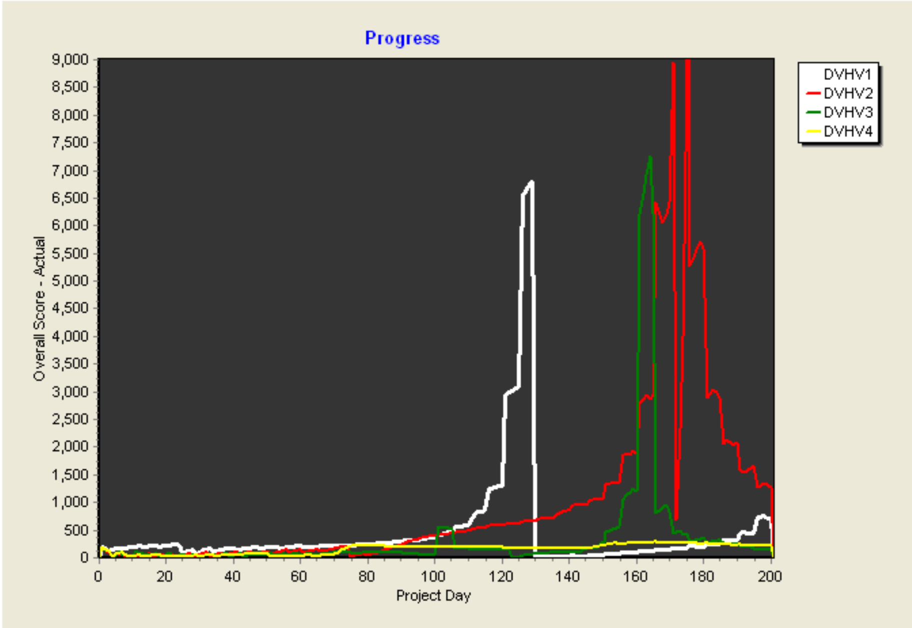


Figure 11.5-19: Summary Measure graph for all 4 runs of the Muck game for student #10

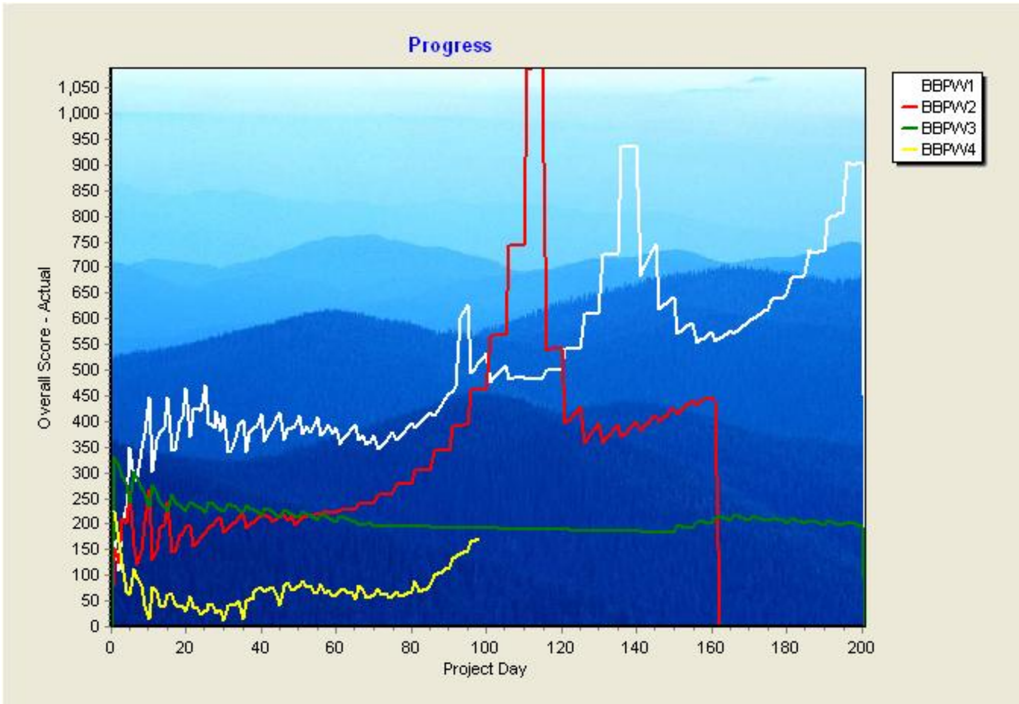


Figure 11.5-20: Graph of Summary Measure for all 4 runs of the Muck game for student #5

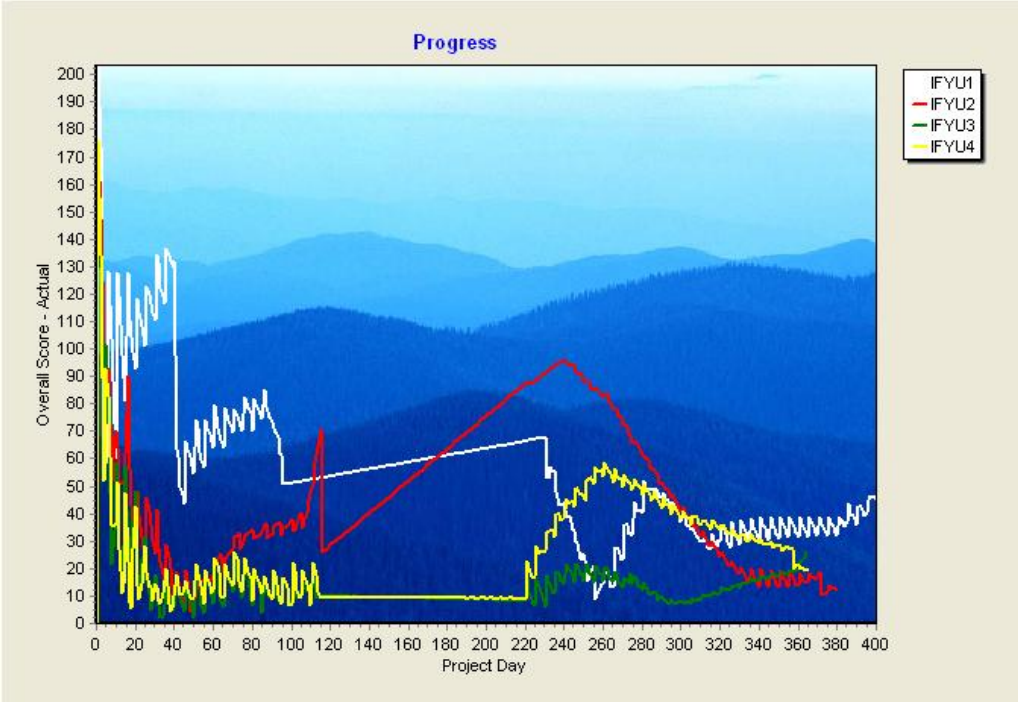


Figure 11.5-21: Graph of Summary Measure for all 4 runs of the Canal game for student #5

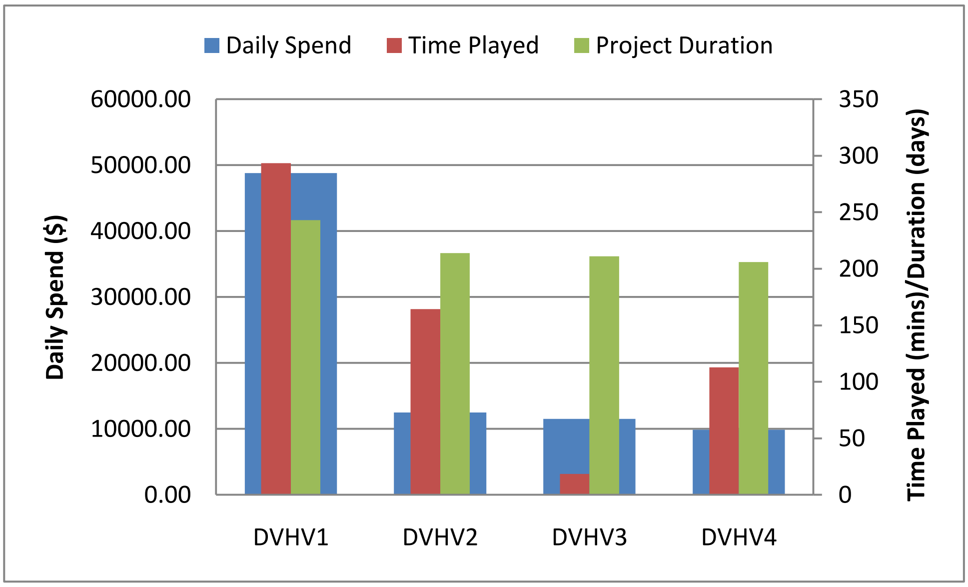


Figure 11.5-22: Chart showing daily spend, time played and simulated project durations for the 4 runs of the Muck game for student #10

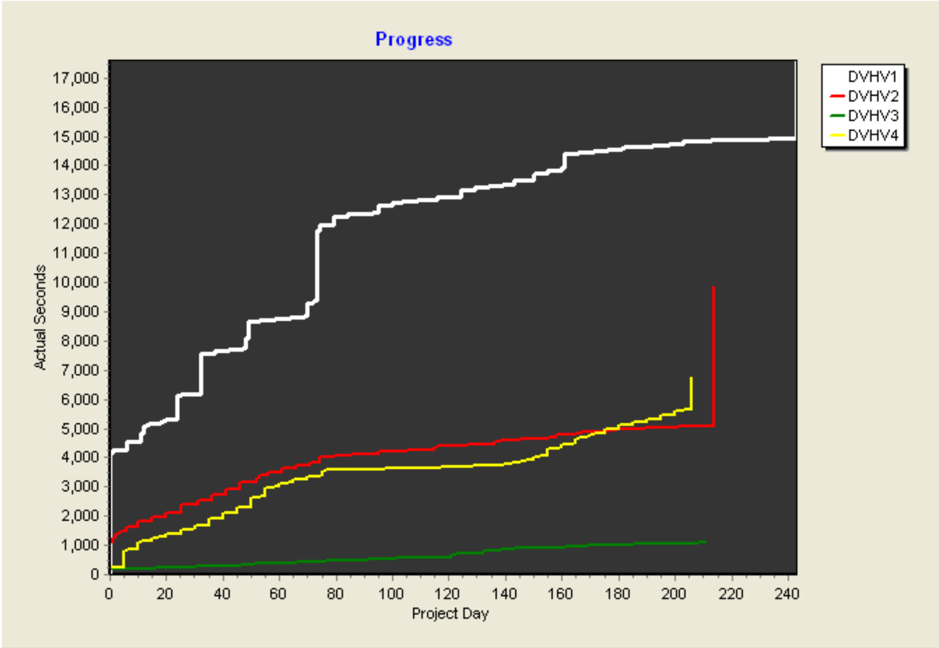


Figure 11.5-23: Graph of actual time against simulated duration for all 4 runs of the Muck game for student #10

K. Timetable for Management for Positioning Technologies teaching module

Time	9am - 10am	10am - 11am	11am - 12pm	12pm - 1pm	2pm - 3pm	3pm - 4pm	4pm - 5pm
Monday	Introduction to module	Business planning summary	Briefing on business plan preparation	Introduction to Management	Work group formation and development of concepts	continued	continued
Tuesday	Introduction to planning	Types of Plan	Planning tools and techniques	Guest Speaker - Banking and Finance	Project Planning	Planning and Risk	Concept report from work groups
Wednesday	Introduction to Finance	Financial Assessment	Sources of Finance	Guest Speaker - Management of a small business	Group work - development of business plan	continued	continued
Thursday	Introduction to Control	Control Techniques	Organisational Theory and Practice 1	Guest Speaker - Surveying Industry	Organisational Theory and Practice 2	Group Work	Group Work
Friday	Group presentations of business plans	Presentations continued	Presentation - simulation game	Module Evaluation			

Figure 11.5-24 : Timetable for the Management for Positioning Technologies (MPT) module

L. *Gantt chart for Tingham Tank Farm project (SubCon simulation game trial)*

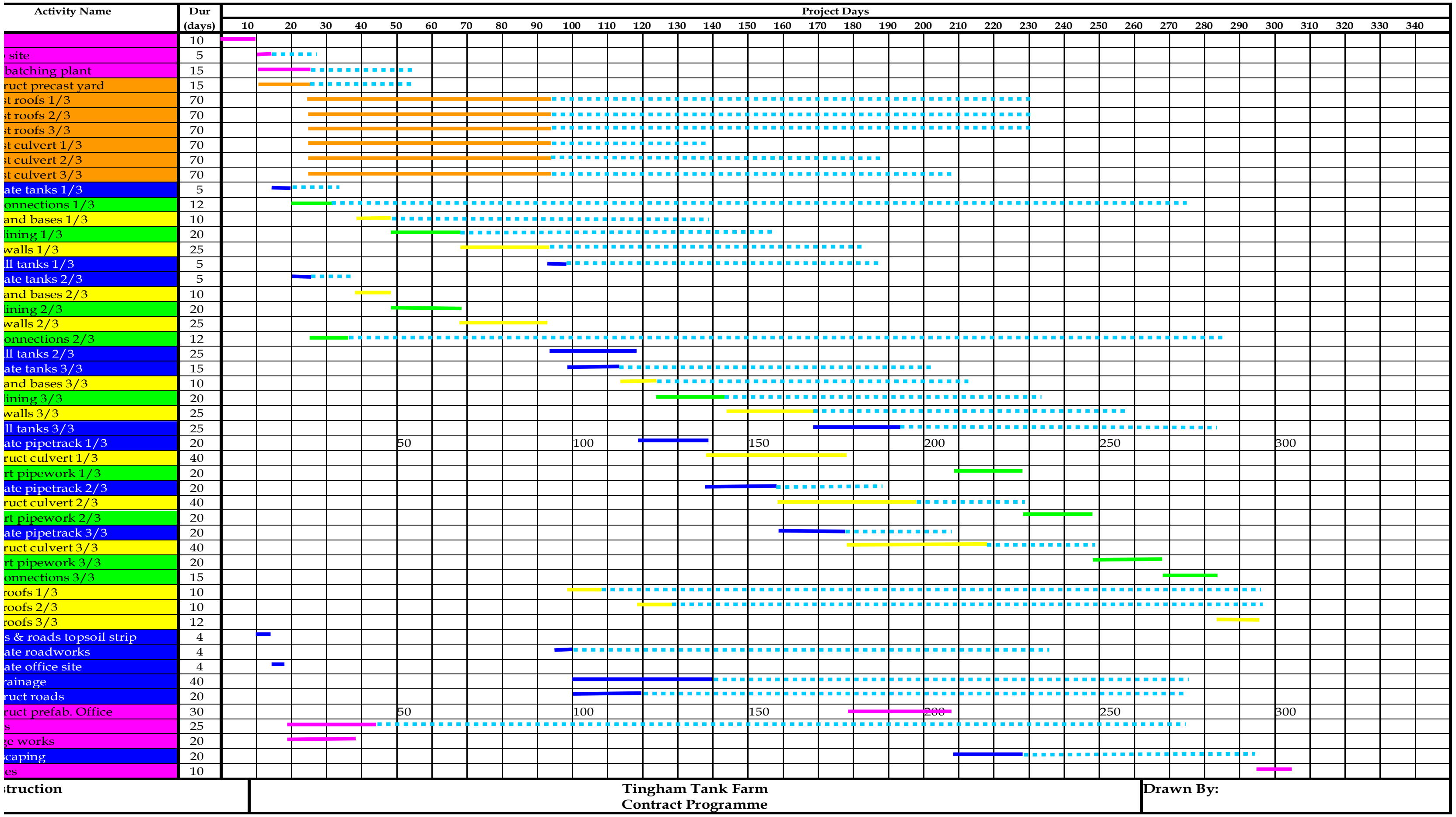


Figure 11.5-25 : Programme of work for Tingham Tank Farm project with subcontractor roles assigned