AC 2010-1873: EFFECTIVE TEACHING OF COMPLEX MANUFACTURING TOPICS TO UNDERGRADUATE ENGINEERS UTILIZING A NOVEL, BROADLY BASED, INTERACTIVE VIRTUAL COMPANY

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Effective Teaching of Complex Manufacturing Topics to Undergraduate Engineers Utilizing a Novel, Broadly Based, Interactive Virtual Company

Abstract

The research program which is described in this paper was designed to investigate a methodology by which improvements could be made in the delivery of complex, ill-defined domains in engineering such as manufacturing systems and engineering management. In particular, to more successfully expose students to industry typical indeterminate problems and to give students experience in their solution. It was hoped, furthermore, to increase student levels of engagement and motivation with the topics presented.

This research study applied an educational intervention based upon a comprehensive, simulation of a manufacturing enterprise to engineering students. The course chosen as a 'test-bed' for this educational intervention was a third-year, one-semester, course in manufacturing systems, part of a four-year undergraduate degree in mechanical engineering, at the University of Auckland.

Analysis, in the form of an interpretive, qualitative study was carried out with the methods of data collection including group and semi-structured interviews, questionnaires and researcher observation. The research program did not attempt to measure 'learning' by means such as test and examination based quantitative assessments.

The finding was that this simulation, built on a situated learning framework and offering authentic content within a realistic context, increased levels of student engagement, motivation and willingness to accept the validity of the indeterminate problems presented to them.

Introduction

The education of prospective engineers in undergraduate degree courses is carried out, in the main, by the delivery of topic materials via lectures, tutorial sessions and practical laboratory experiments. The traditional lecture is usually complimented by the use of printed lecture notes and/or a textbook. Reinforcement of the material is generally attempted by presenting students with textbook problems in which the data required to solve the problem is presented unambiguously and in its entirety. There is ongoing debate about the effectiveness, or otherwise, of this traditional didactic teaching approach and Hargrove and Dahleh [1] believe that engineering educators must develop more innovative methods for learning in order to replicate real-world problem solving. Indeed, many practitioners have supplemented their lectures and tutorials with project-based and problem-based learning activities in an attempt to provide variety and alternative learning mechanisms for students [2-6].

The problem with this procedural approach to problem solving is that it is not representative of the methodology required for many real-life engineering problems. Here the data are often vague, contradictory and perhaps out-of-date and there are generally many ways to go about solving the problem and many possible answers. This multifariousness demonstrates what Ferguson [7] calls, “the incalculable complexity of engineering practice in the real-world”. Undergraduate degree students need to be able, or at least begin to be able, to deal with ill-defined problems, make decisions about which data to utilise, be able to accept approximations, and to simplify problems by neglecting inconsequential issues.

These sorts of problems are particularly prevalent in ill-defined domains such as engineering management or manufacturing systems. An ill-defined domain is categorised by Lynch, Aleven, et al. [8] as one in which there is a lack of a systematic way in which to determine if a proposed solution is optimal, and by King and Kitchener [9] as one in which problems cannot be described with a high degree of certainty or completeness.

Commenting on university courses in manufacturing, Sanderson [10] says that, “the type of analysis, modeling and decision-making required to integrate manufacturing into real-world applications are beyond the scope of traditional lecture and textbook materials”, whilst Dessouky [11] writes that, “traditional pedagogy in manufacturing [courses] is ill-equipped for the task”. Woolf et al. [12] maintain that, “New tools that go beyond simple classroom lectures are desperately needed in [manufacturing] engineering education”. As a recently graduated engineer reported in the course of an interview [13], “It is kind of a sore spot with me that educational institutions teach that when you do your work there is a right answer and a wrong answer. And in the real world it is never that way, there are many ways to do things and it is not a matter of getting a right answer it’s a matter of working for the best solution for your particular situation”.

Narrative and Simulation Fidelity

Abrahamson [14] believes that storytelling forms the foundation for education and claims that putting teaching material into a form of narrative helps students to think in a crucial manner and make their learning experiences more personalised. He does not review the issue of student motivation but one could expect that increased personal identity with the material presented to them would have the effect of increasing student levels of interest, engagement and motivation.

Schank and Abelson [15] go so far as to say that virtually all human knowledge is represented in terms of stories. They write, “It is hard to remember abstractions unanchored in specific experiences, but it is relatively easy to remember a good story”. Bruner [16] believes that narratives are vital for humans and that narrative is “a mode of thinking, a structure for organizing our knowledge, and a vehicle in the process of education, particularly science education”. He argues that in education the sciences have severely neglected the use of narrative and it seems likely that the same criticism can be levelled at engineering.

It appears that the careful use of narrative, to place some context and ‘reality’ around the course topics presented, could provide a more natural way of learning than the usual engineering course delivery methods of lectures, conventionally formatted PowerPoint presentations and topic specific handouts.

Thus, in seeking to address the issues discussed earlier in this paper, this research initiative employed the tool of narrative more extensively than other examples of manufacturing education interventions discovered in an examination of the literature. The intervention was designed to provide a coherent and logical structure, or story, which would allow the integration of a range of topics which otherwise appear to students to be disconnected. The narrative scenario was designed to be realistic, comprehensible and valid in order to establish the bona fides of a virtual enterprise. It was to be comprehensive enough to be realistic but not so complex as to render the intervention less flexible when used by other practitioners for other ill-defined domains.

The aim of the intervention designed for the manufacturing systems course was to persuade students to undertake what Samuel Taylor Coleridge called the "willing suspension of disbelief" and accept the fiction that they were consultants to a virtual enterprise. This suspension of disbelief was facilitated by means of a unique level of attention to detail, the avoidance of inconsistencies in the narrative and supplementation with authentic realia. This detailed scenario made it possible for the students to accept the role that the intervention offered them – that they were working on real problems for a real company within which it was possible for their solutions to be adopted, by the organisation. This acceptance, making their efforts and results important and worthwhile, and their decisions a serious matter not to be undertaken lightly.

The products to be manufactured by the virtual enterprise products were selected to be of a type which would typically be manufactured in small to medium quantities and be consistent with the company's location and likely markets. The products were also required to be technically complex in order to have some intrinsic interest to students and require a broad spectrum of manufacturing technologies to produce.

After examining a number of alternatives it was decided that the virtual company would manufacture a range of fire protection equipment. In particular, it would manufacture smoke and flammable gas detectors for commercial applications. These products incorporate the application of a range of fundamental engineering topics, such as pneumatics, control systems, thermodynamics, and their production required a mixture of design disciplines and a varied range of manufacturing methods.

The virtual enterprise was named 'Team Detectors Limited' and manifested as a web site on a commercial ISP's web server. It contained four simulated departments: Design Office; Planning Office; Quality Assurance Laboratory; and Administration. Communications between the virtual enterprise and students was to be carried out in such a way as to mimic as closely as possible the way that communications are carried out in the workplace. That is, by a mixture of e-mails, e-memoranda, paper documents and data on web site pages.

The realia created to add corroborative detail included:

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

Research Methodology

There has been some debate in the educational community about the fact that the results of randomized control trials (RCT's) seem to be having little beneficial flow-on effect to educators' practices in the classroom [17]. Scriven [18] has written that, "there are many issues of great importance in education ...where it is ethically and/or practically impossible to use RCT's" whilst Wolfe and Crookall [19] maintain that classically acceptable experimental research, as used in the physical sciences, is impossible to duplicate in realistic educational situations.

A problem with randomized, control trial, experimental methods is that in many situations it is not possible for some of the method's criteria to be met. For example, it may not be possible to randomly select subjects for a control group which would not receive the intervention. It may also be impossible to exclude various random influences on the student groups. Wankat et al. [20] maintain that, "It is almost impossible to construct an educational research study in which potentially confounding factors can be clearly identified and their influence eliminated..." (p. 91).

These issues, concerning randomly selected control-groups and the elimination of extraneous variables, apply also to the particular circumstances of this research program. There is one stream of third-year engineering students only in the course under review, and for reasons of ethics, staffing, teaching space and timetabling the utilization of a control group was infeasible. The lack of a comparison group that closely matched the cohort of students of interest prevented also the use of a quasi-experimental design.

In addition it was not possible to control for learners' prior knowledge and experience. These are clearly significant covariates when using, for example, grades as the dependant variable to assess the effects of the intervention. These independent variables, together with the fact that the intervention grew and changed markedly over several summer semester applications, made it impractical to use previously taught classes as a control.

Thus the character of the course under investigation indicated the use of a qualitative, interpretivist research method now common in the fields of education and social sciences.

This work adopted a 'design-based research ' methodology which adopts an action, interventionist and iterative posture to learning research. It is centred on the participants of the study and collaborates with them. It uses ongoing, in-situ, monitoring of the sources of success or failure of various versions, or iterations, of a designed teaching intervention to provide immediate or, at least, timely feedback on the results of the process Van den Akker [21]. Cobb et al. [22] emphasize the iterative nature of the process, “The design content is subject to test and revision, and the successive iterations that result play a role similar to that of systematic variation in experiment”.

Shavelson et al. [23] graphically describe the methodology as being, “…carried out in educational settings, seeking to trace the evolution of leaning in complex, messy classrooms and schools, to test and build theories of teaching and learning, and produce instructional tools that will survive the challenges of everyday practice”.

The methodology can be likened to the design and testing of a product in engineering. The educational intervention (c.f. product) design cycle begins with a product concept based upon relevant pedagogical theories (cf. engineering fundamentals). This is followed by the creation of a first working intervention (cf. product prototype). The prototype is then tested and the data collected during the testing is used to refine the design. This cycle of design, test and re-design is carried out as many times as required. In fact, as in product design and production, the cycle may never be completely terminated.

In interpretative qualitative studies, such as the present work, the issue of internal validity requires to be re-examined. Guba and Lincoln [24] suggest that internal validity is basically a measure of the way that things really are and how they work and suggest a new criterion, 'credibility', which is more meaningful within a constructivist inquiry. They define credibility as the extent to which the research study findings represent not "a presumed 'real' reality, out there somewhere", but rather the multiple constructs that are held by the students in the study. Techniques suggested for increasing the credibility of results and which were adopted for this study are:

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

Pedagogical Frameworks

The structure of the intervention was based upon the pedagogical framework of situated learning, or situated cognition, which has become an important pedagogical theory since it was first proposed by Brown, Collins and Duguid in 1989 [25]. These researchers maintained that items of information cannot be remembered as freestanding and abstract entities of information to produce a successful learning outcome *unless* they are situated in a real-world context in which the problem is relevant.

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

In a later work Herrington [26] defined the critical features of situated learning for computer-based instructional design and wrote that situated earning environments must, together with other elements, provide an authentic context that reflects the way the knowledge will be used in real-life and provide, also, authentic activities that mirror real problems. Other elements included providing authentic context that reflects the way knowledge will be used in real-life, providing authentic activities, providing multiple roles and perspectives for students to observe, and assisting the collaborative construction of knowledge with peers and others.

These elements were used as guiding design criteria in the design of the virtual enterprise, its delivery by practitioners and the included student tasks.

The Intervention Development

Following a successful pilot run of an initial design of the concept the intervention was applied to the manufacturing systems course over four summer semesters. During this time the intervention was expanded to cover all of the topics included in the course, the narrative scenario was expanded and more corroborative detail added. Where required, existing features were amended following student feedback or researcher observation.

Table 1 summarises the development of the intervention over this period and the expanding range of topics included.

Table 1: Virtual Enterprise, Record of Iterations

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

The indeterminate problems, to be presented as tasks for students, were set within scenarios conceived so as to be situated, validly, within the overall virtual enterprise narrative. The word ‘tasks’ was used in this program as being more appropriate than the usual terminology of ‘project’ or ‘assignment’. To emphasize the interconnectedness of the topics the data utilised in a new task included information generated by the student in a previous one. For example, the yearly sales target for the virtual enterprise, which is an element of one of the tasks, must be consistent with the achievable output of the designed manufacturing system, which itself is based upon the production rates achievable by the machines and operators, which in turn are a function of the machines used and the factory layout. Thus, the data set used for the tasks is a complex web of interconnected data, facts, figures and systems.

The level of indeterminacy was set such that the tasks would pose a challenge to students but not too much of a challenge. Care was taken not to make the tasks appear too difficult to students unfamiliar with manufacturing systems and its topics. Making the tasks too difficult would have had a detrimental effect on motivation since students are more motivated by tasks in which they expect to do well. Students felt that the tasks simulated real-life jobs accurately and this perceived relevance of the material to future careers was also a motivator.

The tasks followed a logical sequence both in engineering and chronological terms and, in fact, may be viewed as one large, single, manufacturing system activity. This characteristic meets one of the requirements of situated learning theory, i.e. that tasks provide a complex, coherent and sustained learning environment. Barab [27] points out that authenticity is provided by the dynamic interactions amongst all the components [of the virtual enterprise] and that, "authenticity is manifest in the flow itself….and not in any one feature in isolation."

To successfully deal with the indeterminate problems the students were required to frame the problem cognitively, assess the different solutions, select a likely 'good' solution and be able to justify the selection. The tasks could not be completed by applying a constrained set of rules, such as might be used to complete a text book problem or examination question, and most tasks required the use heuristic methods.

The tasks included in the intervention were:
1) Plant Layout: Students were given the task of designing the layout of the manufacturing facilities on a new site. They received a report from the company's managers describing the departments which were to be re-located, their function, approximate floor area, and any co-location restraints between them. This report had some inconsistencies deliberately included to ensure that the co-location requirements could not be met in total without compromises. To increase the level of ill-definition the positions of some departments on the site were implied by their function rather than being explicitly stated. A portion of the product assembly area as set out by a student is shown below.

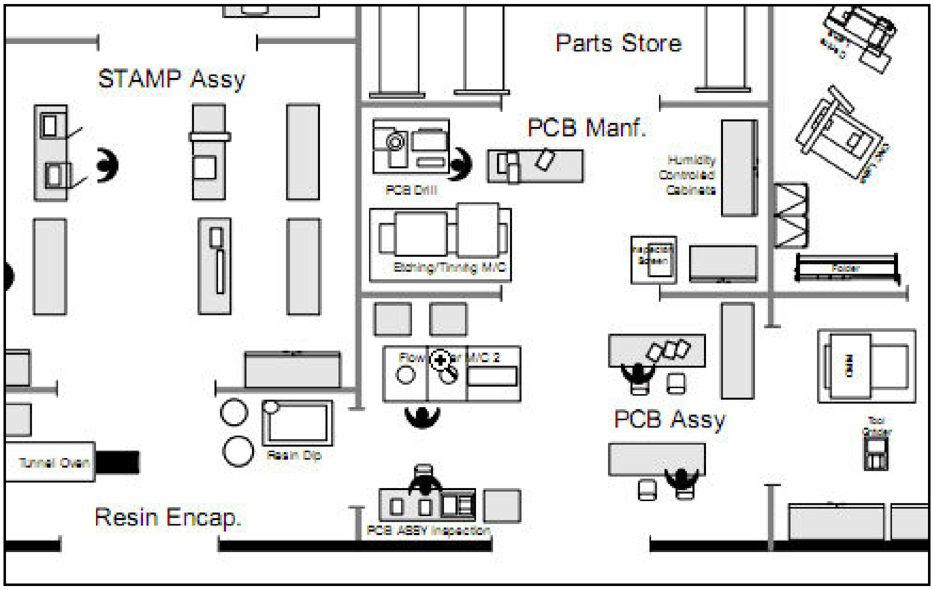

Figure 1: Example of Student Completed layout

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

3) Ergonomics: An ergonomic analysis and re-design of a factory workstation which was unacceptably stressful for the operators (video clips of a real, and ergonomically poor, pallet unstacking operation was used in this exercise). Students used a professional software package, ErgoEASE®, to perform the ergonomic analysis.

4) Pull System Simulation: Having laid out the plant and simulated likely production rates students were then given the task of utilizing finite capacity scheduling concepts to schedule a numbers of orders through the Team Detectors plant in such a way that the customers' required delivery dates were met. Students used Preactor®; a popular computer based scheduling system. The students' task was to distribute the workload among work centers and decide which job processing sequence to use in processing customer orders

Data Collection & Results

As explained in the Methodology section this research programme was designed to influence student learning by increasing levels of motivation and engagement with the course. It did not attempt to measure 'learning' by means such as test and examination based quantitative assessments. However, these attributes of motivation and engagement are generally regarded as important drivers, or precursors, of learning and it is expected that promotion of these attributes would also promote absorption and retention of the topic material. Without them learning, if it takes place at all, will be of a shallow and transient kind.

The data collection instruments consisted of an anonymous questionnaire containing a quantitative Likert scale, semi-structured interviews with member checking (reading back, transcripts for confirmation of accuracy), and researcher observations including random activity sampling. The use of different methods to collect data allowed the researcher to collect multiple perspectives on the design of the intervention and of students' perception of its utility. The data was used to assist in determining the extent to which the intervention design met its goals of improving the delivery of a manufacturing systems course occupying a complex, primarily non-quantitative and ill-structured domain.

Information obtained from the data collection activities was used to modify and improve the design between applications in accordance with the principles of the design-based research methodology adopted for the project.

1. The Questionnaire : The data from the questionnaire are shown in Table 2.

Table 2: Student Questionnaire Responses

Question (N = 43)	Strongly Agree (No.) (%)	Agree (No.) (%)	Undecided (No.) (%)	Disagree (No.) (%)	Strongly Disagree (No.) (%)
The use of a real industry scenario added interest to the tasks.	13 (30)	18 (42)	6 (14)	4 (10)	2 (5)
The use of a real industry scenario added relevancy to the tasks.	14 (33)	19 (44)	6 (14)	2 (5)	2 (5)
I became more interested in the course material because of the company scenario.	10 (23)	17 (40)	9 (21)	5 (12)	2 (5)
The Team Detectors concept helped in understanding how the components of a manufacturing plant and its systems work together.	9 (21)	24 (56)	5 (12)	5 (12)	0 (0)
The Team Detectors concept enhanced my understanding of the lecture material.	7 (16)	19 (44)	9 (21)	4 (9)	4 (9)
I would recommend that the concept of industry based scenarios be extended to other engineering topics.	16 (37)	15 (35)	7 (14)	1 (2)	3 (7)

Table 3 : Student Questionnaire - Merged Responses

Question	Positive Responses %	Negative Responses %
1	72	15
2	77	10
3	63	17
4	77	12
5	60	18
6	72	9

2. Interviews: The following quotations are a sample of the comments mad by students during the interview sessions, and the observed tutorials during which the students used the appropriate software to complete their tasks. To aid analysis they have been grouped into five categories, matching the situated learning framework elements adopted – student perception of verisimilitude, level of immersion, promotion of engagement with the course, indeterminacy of task solutions, dissenting voices.

Student Perception of Verisimilitude

"Good idea, the Team Detectors. I did not pick up on it not being a real company until late on in the course."
"Well, really, I thought it was a real company. Wow, it was very realistic."
"I though the Team Detectors company was a real company for a long time."

Level of Immersion

Two students felt that they had been getting too involved and spent more time on the tasks than they would have had the tasks been presented "ordinarily". Among the comments received were the following:

"I spent much more time on this than I would have on a paper problem."
"It's like having a new job at a company."
"The Team Detectors concept was good and the exercises were interesting. It's a bit like having a job."
"I felt I was acting like a pro."

Promotion of Engagement

Observations were made of the students' interaction with the intervention from the point of view of how engaging they felt the scenario to be. Observations made of student-to-student interactions recorded such asides as "I have to deliver this detector by the due date or I will be in trouble" which indicate a satisfactory level of identification with the company's virtual staff.

"Yeah, it was OK, it was different and I thought it was interesting."
"This is good. It is much more interesting than sitting in a lecture."
"It's weird. At home I kept thinking that if I have one more go at it [the simulation task] I might get a better result. It's a bit addictive."
"I like these problems. They're a bit more like real ones. In other classes you're just putting numbers into formulas."

Many comments were made about the use of the video clip of a real workplace operation in the ergonomics task and students expressed empathy with, and sympathy for, the hardworking operator in the video clip. Although they had never met, her several students remarked that at the end of the exercise they felt that they knew her well:

"I felt really sorry for her."
"You know, I really wanted to help her out, silly because it's only an exercise."

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

Indeterminacy of Task Solutions

Opinions were varied, vague, and sometimes non-committal, on the issue of tasks dealing with ill-formed problems containing some vagueness in the task specification. However, a number of thoughtful contributions were made including:

"Digging the thing that was actually wanted out of the project memos was hard. I was annoyed at first but that's what happens at work I suppose. So I suppose it's real."
"The task of the facility layout was good as it was hard to know if you should treat it as a typical university project or think outside the box and have a risk of not doing what was wanted."
"We had to think about what was relevant, like in a real job."

Discussions with students indicated that many were somewhat disconcerted when faced with problems presented in any manner other than the typical condensed, non-textualised, text book/examination question format. This unease was, on occasions, expressed with some frustration in comments such as:

"What exactly do you want?"
"But which answer is the [emphasis] *correct one?"*

There were some dissenting voices:
"Nah, I don't like computers too much. I prefer just the basic information really."
"If you don't mind me saying so. I didn't pay that much attention to it to be honest."

Not all students became involved:

"Involved? Not really. It might just be my approach I just look at the assignment and do what is wanted."
"I only gave a quick look at the extra [corroborative] *material."*

3. Researcher Observation and Random Activity Sampling

Observations were made of the students' interaction with the intervention to determine how immersive they felt the scenario to be. These observations made it clear that some immersion had taken place through such remarks such as *"I have to deliver this detector by the due date or I will be in trouble"*.

For the random activity observations the class was split into three groups for their laboratory sessions and the activities of five (randomly selected) students in each session were recorded. A high percentage of the time (45%) students were recorded as working on the task with enthusiasm and motivation and immersed in the task (Production Scheduling) and 21% of the time working with a team member.

The full figures were:

45% - Immersed in task.
21% - Working on task with a team member.
16% - Listening to other student talking on task.
18% - Uninvolved in task (talking off task/unrelated material on computer screen).
5 events - Moving to help another student.
6 events - Asking other student for comment.
8 events – Asking other student for help.
3 events - Makes negative task comment.

Discussion

Data from the anonymous Likert questionnaire shows that the percentage of students who thought that the virtual enterprise scenario added interest and relevancy to the tasks/assignments was high 72% and 77% respectively. Similarly most students agreed that the intervention assisted them to understand the integrated nature of the topics covered. This data was cross-supported by the responses to the interview questions such as:

"Yes, I thought Team Detectors was good it made a whole bunch of theories more interesting. It put an image in my head and helped me remember."
"What I liked was the way the tasks joined together. That made them make sense, yes. …much better than ordinary lecture test questions."

During the collection of data by observation students were seen to work in informal teams (of two, generally) to approach the problems given and assist each other with applying the software, an example of distributed cognition. For the scheduling task, selecting the best combination of products, customer orders and production schedules lead to some very animated students. They became extremely involved in the problem and quite concerned if one of their customers appeared likely to receive a late delivery. The random activity exercise revealed that students spent a significant part of their time (37%) in collegial collaboration and negotiating a common 'best' solution for submission. This activity is an important and desired outcome from a situated learning framework.

This observed behaviour was consistent with the responses to the intervention measured by the other sources of data and assisted in obtaining confident in the trustworthiness of the data obtained.

The data indicating that the virtual enterprise intervention had succeeded in raising levels of interest, motivation and engagement and was able to get students to undertake a 'willing suspension of disbelief'. Nevertheless, the students seemed at the same time to keep one eye on what the lecturer/assignment marker wanted. This stance was demonstrated by questions to the observer such as "This isn't very clear, what exactly do you want in my answer?" The academic environment thus appears to mediate against attempts of making the tasks totally immersive, at least for some students. In was clear that, whatever was said about playing the role of a consultant to the virtual company, the final objective, as far as some students were concerned, remained to satisfy the marker and get a good grade. This reaction is understandable since the environment the students have been in at university since their commencement of degree studies has been to do what the marker wants and get marked appropriately. As one student remarked, "that's really the reality".

If the classroom will always be the classroom, where learning is done, and the ‘real-world’ will always be a separate ‘world’ where the professionals work, then considerable effort clearly has to be put into attempts to designing immersive and authentic virtual worlds which will eliminate the separation of learning activity from simulated authentic professional activity.

Conclusions

The data collected during the research program indicated that the Team Detectors intervention was successful in meeting the research goal of improving the delivery of a course of a complex non-numerical nature e.g. the University of Auckland course in manufacturing systems for Year-Three Mechanical Engineering students.

The results indicate that this immersive, multimedia based, intervention was successful in increasing level of student interest in the course topics, in raising levels of immersion and enthusiasm and was also successful in conveying to students the indeterminate nature of many manufacturing systems problems.

It is hoped that the outcome of this current research will provide a tool to assist engineering educators to incorporate computer-based multimedia and immersive elements into their manufacturing systems and engineering/operations management courses. The intervention will give them a proven and successful virtual environment to use as a ‘workbench’ which they may adapt to their own requirements. This intervention has been packaged on a DVD and is available for use by other practitioners.

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