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# The Application of Social Learning Theory and Communities of Practice to a Complex, Ill-Defined Domain in Engineering*

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*This article describes a research programme which utilised Bandura's Social Learning Theory and Lave and Wenger's Communities of Practice as components of a pedagogical framework for the design and application of a teaching intervention in a manufacturing systems course. This course occupies one semester of the third-year of a four year undergraduate degree in engineering at the University of Auckland, New Zealand. The novel teaching intervention described here took the form of a multimedia-based virtual manufacturing enterprise set in a complex authentic context. This article describes the design of the intervention and presents the data collected on the students' experiences with the virtual organisation.*

**Keywords:** manufacturing education; social learning theory; communities of practice; virtual enterprise; computer-based multimedia; Simulation; ill-defined domain

## 1. INTRODUCTION

THE UNIVERSITY of Auckland course in manufacturing systems is part of a four-year undergraduate degree in mechanical engineering. This course was the subject of the educational research programme described in this article because the topics within it are generally regarded as complex and ill-defined and, as such, have historically presented some problems in teaching them effectively. The course contains topics such as: plant layout; material handling; manufacturing information systems; manufacturing systems modeling and simulation; industrial ergonomics and work standards; production planning and scheduling; line balancing; quality systems and lean manufacturing.

The domain of manufacturing systems is described as complex because it covers a range of disciplines including, for example, operations research, operations management, psychology, human physiology (ergonomics), mechanical engineering and control systems. The domain is considered to be ill-defined meeting as it does McCarthy and Minsky's [1] definition of an ill-structured domain as one in which there is a lack of a systematic way in which to determine if a proposed solution is optimal (quoted by Lynch, Aleven, et al [2]). King and Kitchener explain [3], p11, that a problem can be considered ill-structured if it cannot be described with a high degree of certainty or completeness and where, 'experts may disagree about the best solution, even when the problem may be considered solved'.

It was believed that these characteristics of the manufacturing systems course (ill-definition, multiple possible solutions, and the common use of heuristics, or rules-of thumb, rather than classical numerical methods) led to students believing that the subject was not scientific in the way that, say, mechanics or thermodynamics are. The number and variety of disciplines covered also presented students with problems in comprehending the discipline in an integrated manner. It was clear from formal course feedback results and discussions with students, that they viewed the course primarily as a series of disconnected topics. This was of concern to the teaching staff as a manufacturing system is an integrated and complex one and an appreciation of this fact was an important and desired outcome for the course. Secondly, perhaps as a result of their failure to see the course as an integrated whole, the level of student motivation, and engagement with the material covered in the course was low. The effect of these factors was reflected in the feedback received from student interviews and from formal course feedback which indicated that the students thought the topic area was 'generally boring, unscientific and not very relevant' [4].

Sanderson, et al [5], write that, 'Many aspects of manufacturing education do not lend themselves to traditional approaches to organization and

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presentation of materials. Manufacturing is a dynamic and interdisciplinary environment, and the types of analysis, modeling, and decision-making required to integrate design and manufacturing in real-world applications are beyond the scope of most lecture and textbook materials.'

Many students in manufacturing courses are described by Woolf et al. [6] as, 'bored, uninterested and unmotivated, particularly when enrolled in their one required 'show and tell' type undergraduate course dealing with manufacturing processes', whilst Jackson [7] points out that, 'Not all students are well served by the serial, abstract presentation style . . . that characterizes most engineering programs. Some students need a context in order to grasp topics'.

In an effort to deal with the issues of relevance and engagement, and to vary the traditional lecture-based delivery method, many university engineering departments have adopted an industry-project based learning approach, or have utilised hands-on design and build projects as described by Jensen, et al, [8] and Seidel and Tedford [9]. The aim of these initiatives is to allow students to get first-hand experience of actual manufacturing systems and processes whilst at university. These programmes have had encouraging results at the University of Auckland with positive student feedback and significant gains in conceptual learning [10]. However, this project-based approach, whilst useful as far as it goes, does not generally solve all of the problems associated with providing the best possible learning experiences for students. Whilst students may discuss their assigned project with the managers in the host company, and obtain first-hand information about the company's organisational structure and culture, they are generally not exposed to, and do not have time to explore, the full range of activities within the organisation. As explained by McCarthy [11] and Dessouky [12], the complexities and integrated operations of a typical manufacturing company are, generally speaking, not fully experienced or understood. These considerations lead to the formulation of the following, multi-part, research question to be investigated by the narrative-led, computer-based educational intervention which is the subject of this paper:

> Can the current[1] delivery of complex non-quantitative topics such as manufacturing systems be modified to increase (a) student engagement, (b) enthusiasm and (c) student capability to perceive them as coherent and scientific bodies of knowledge?

This research programme was not designed to influence student learning directly or to attempt to measure 'learning' by means such as test and examination based quantitative assessments. Its aim was to design an educational intervention based upon the work of Bandura, Lave and Wenger which would promote enthusiasm and engagement with the domain of manufacturing systems. However these attributes 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.

[1] In this context 'current' refers to the teaching methods and student attitudes to the course prior to the commencement of the research programme.

## 2. APPLYING A RELEVANT EDUCATIONAL PHILOSOPHY

Workplace engineering activities are usually carried out in a team environment and this makes Bandura's Social Learning Theory of relevance to practitioners in engineering education who are seeking to base their teaching upon a recognised pedagogical theory. In contra-distinction with the conventional behaviourist theory of a 'stimulus-response-reinforcement' sequence in learning, Bandura believed that individuals learn by observing others, whom they believe are credible and knowledgeable, with or without reinforcement. According to Bandura [13], page 22:

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

Building on Bandura's work, Rogoff & Lave [14] maintained that items of information could not be remembered as freestanding and abstract entities of information to produce successful learning outcomes unless they were situated in a real-world context in which the problem was relevant. Lave and Wenger [15] developed the idea that learning 'is a process of participation in communities of practice (COP's), participation that is at first legitimately peripheral but that increases gradually in engagement and complexity'. That is, learners initially participate on the fringes of a community of practitioners (e.g. professional manufacturing engineers) moving, with more experience, toward full involvement. Learning is not just the acquisition of knowledge but also a process of social participation in an appropriate group.

Wenger [16] points out that communities of practice posses attributes that are not specifically required in other joint-learning approaches such as team-based or co-operative learning. For example an effective COP requires sustained interaction to develop and places importance on acquiring skills and knowledge from others outside the team or group but who share a common interest in, and attachment to, the domain. Emphasis is also placed on mutually gaining and exchanging expertise rather than delivering a physical product or artifact. Also, one may be a member of a COP even whilst working individually within the discipline (e.g. a sole-practice consulting engineer).

These theories of Bandura, and Lave and Wenger, concerning the way in which learners gain knowledge as part of a group, or team, with a common interest, are complementary. They may be combined and applied within a pedagogical framework known as 'situated learning' provided that emphasis is placed upon working upon authentic practitioner problems in social and participative teams in a real-world authentic context.

Situated learning, or situated cognition, has become an important pedagogical theory since it was first proposed by Brown, Collins and Duguid in 1989 [17][16]. The theory of situated learning proposes that knowledge and skills are learned in the contexts that reflect how knowledge is obtained and applied in everyday situations (cf. Lave & Wenger). It requires that inquiries into learning and cognition take serious account of social interaction and physical activity (cf. Bandura). 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.

From this brief discussion of Bandura's Social Learning Theory and Lave and Wenger's Communities of Practice it appears that their emphasis on the social and authentic contexts of learning offer a pedagogical framework within which an intervention could be designed to seek answers to the research question posed.

## 3. RESEARCH METHODOLOGY

In considering a methodology by which the performance of the intervention could be assessed it had to be kept in mind that in the particular circumstances of this research programme it was not administratively possible or ethically desirable, to split the student cohorts into 'intervention' and 'non-intervention' groups for the purposes of conducting randomised control trial experiments.

The intervention was administered over a period to a number of cohorts and it was not possible to control for students' level of prior knowledge and so grade comparisons between cohorts was problematical. A further confounding factor was the fact that during the course of the research programme the amount of student contact was increased. The number of lectures in the course was increased from 24 to 36 with a corresponding increase in tutorial time and the number of student tasks making it difficult to compare cohorts. The students had, almost without exception, entered the degree programme directly from high school and, apart from a few hours of practical experience during their holidays, had no industrial experience.

As Wankat, Felder, Smith, and Oreovicz explain [18], 'It is almost impossible to construct an educational research study in which potentially confounding factors can be clearly identified and their influence eliminated'. Borrego [19], page 91, points out that there are differences between the fields of engineering research and educational research which preclude the application of conventional engineering research standards of rigor to engineering education research.

A design-based research methodology offers a valid way out of this bind. The general characteristics of design-based research have been the subject of a number of books and journal papers in recent years. The most often cited works being those of Brown [20] and Collins [21], Kelly [22], the Design-Based Collective [23] and Reeves [24] who describes design-based research as a pragmatic epistemology that regards theory as being collaboratively shaped by researchers and practitioners. He writes 'The overall goal of [design-based] development research is to solve real problems while at the same time constructing design principles that can inform future decisions'.

Design-based research adopts an interventionist and iterative posture to learning. It uses ongoing, in situ, monitoring of the sources of success or failure of various versions of a designed teaching intervention to provide immediate, or at least timely, feedback on the results of the intervention (where the intervention may be any one of a number of influences on the learning environment). Shavelson, et al [25], p25, described the methodology as ' . . . based strongly on prior research and theory and 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 to produce instructional tools that survive the challenges of everyday practice.'

A key characteristic of the methodology is the interactive nature of the process as conjectures are generated, and perhaps refuted, and new conjectures developed and subjected to testing. The outcome of the iterative cycle is a framework of theory helping to describe the outcomes and which can be used to specify the focus of investigation during the next cycle of inquiry to inform and improve the application. Design-based research may be undertaken, as in this case, by single workers. Thus, affording the opportunity to observe how research questions, design questions and questions of implementation and revision interact with each other. A further important feature is that the method is both open-ended and seeks information about open-ended questions such as; 'what are the factors that improve student motivation in multimedia courses?' rather than; 'are multi-media methods of presentation better than traditional lectures in motivating students?'

The methodology can be likened to the design and testing of a product in engineering. The educational intervention (product) design cycle begins with a

Table 1. Intervention Iterations and Design Changes

| Version | Features | Available Tasks |
|---|---|---|
| Pilot | Basic web site. Engineering software used Ergonomics (ErgoEASE®). | Ergonomics task. |
| Iteration 1 | New departments added to expanded web site. Simulation facility added using Arena®. | Ergonomics task. Plant layout task. Model & simulate a 'push' production task. |
| Iteration 2 | Enterprise given more of a 'commercial' identity Web site redesigned using CSS and hosted by external ISP. | As above. |
| Iteration 3 | Added finite planning and scheduling facility (Preactor®). New gas detector added to product line. Company Asset register completed. Bills-of-Materials for products added. | As above plus: Production scheduling task. Model & simulate 'pull' production task. |
| Iteration 4 | Full financial and resources database added. Company prospectus published. Miscellaneous other realia added. 3D model of plant developed. | As above. |

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

Design-based research was adopted to provide an accepted methodology by which, rather than attempting to determine the effectiveness of the intervention quantitatively it would be assessed by its success, or otherwise, in changing student behaviour. That is, increased levels of engagement and interest and the ability to be comfortable with topics which are ill-defined and solutions which are indeterminate. The presence of engagement and enthusiasm for the course and topic material was be determined using the data collection methods described later in this article and compared with the attitude to the course displayed by students before the commencement of the research programme.

## 4. THE INTERVENTION

The intervention, designed to incorporate the learning theories previously described and a design-based research methodology, consisted of a multimedia-based virtual enterprise—Team Detectors Limited. The scenario, situated within a rich and consistent narrative, was of a medium sized manufacturing organisation producing a range of smoke detection, inflammable gas detectors and other safety equipment. These products were chosen to suit the required design scenario of an organisation with a mid-range level of output utilising a variety of manufacturing set-ups—continuous flow, batch production and customised job-shop. This product range would use modern technologies in its designs, require a broad spectrum of manufacturing technologies to produce and incorporate the application of a range of engineering topics such as pneumatics, control systems, electronics and thermodynamics. The intervention was first applied as a pilot design and developed and refined over four further iterations following the design-based research methodology, as described earlier in this article. This development programme spanned a period of five years with the intervention being applied to a Manufacturing Systems course running in the second semester. Table 1 gives a concise summary of the changes made to the virtual enterprise and the student tasks over this period. The average size of the annual student cohort during this time was 75.

Most of the student interaction with the virtual enterprise was via the company's web site where they could examine the company's product range and services and receive the technical information required to tackle their student tasks. To increase the fidelity of the intervention the web site, as shown in Fig. 1, was hosted at a commercial ISP, domain name 'teamdetectors.co.nz', rather than on a university network server. E-mail accounts were set up in the names of several, virtual members of Team Detector's management team and students were able to e-mail senior members of Team Detector's staff and receive advice and clarification on any queries they might have.

A novel element of this intervention was the evolution of an extremely comprehensive portfolio of corroborative data to encourage the willing suspension of disbelief by students and to increase levels of immersion and engagement. This collection of realia included a company prospectus containing statements of financial position and financial performance, an asset register containing a complete inventory of all capital equipment, a list of the major employees in the company and a summary of other employees by occupation, a database of customers and outstanding customer orders, bills of materials for the company's

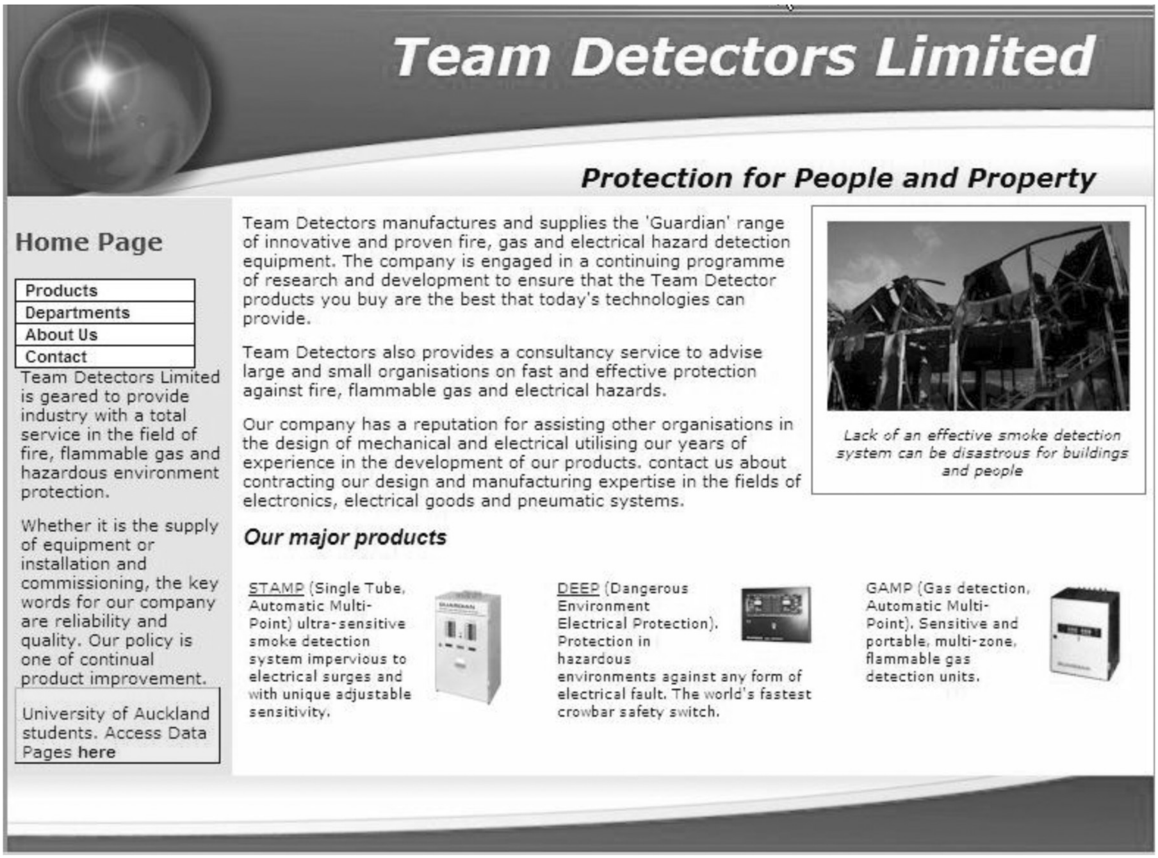


Fig. 1. Team Detectors Limited, Home Page

products, production process sheets and manufacturing drawings for each of the company's products and a 3D model of the manufacturing plant affording walk-through views

The students were given the role of consultants to Team Detectors Limited, who were relocating to a new site, and were set a series of tasks. Note that the term 'tasks' was used in this intervention to describe student exercises rather than the word 'assignments' as it was more appropriate for the workplace 'feel' or environment that the intervention was designed to foster. The tasks formed a logical engineering and chronological sequence from laying out the new plant, to examining new work stations for ergonomic soundness, through to simulation of the efficiency of the new production lines and using finite capacity scheduling to plan the production of customers' orders.

The students were introduced to the tasks by memoranda seeking their help from the senior 'virtual staff' at Team Detectors Limited who also provided all the technical data required. For example machine capacities and machine-hour rates, were viewable and downloadable from pages on the company's web site. The relevant background and theoretical material for the topic was provided by the lecturer via handouts, with supplementary material available from the university's document management system. Also available from the company's web site were a number of video clips. Some of these clips were used to demonstrate real-life applications of the topics covered (such as good, and bad examples of the application of 'lean' manufacturing principles) whilst others were an integral part of the tasks, for example, a video of a real, and unsatisfactory, pallet unstacking operation. This was used to present the problem to be addressed by students in an ergonomics task.

The use of consistent and authentic scenarios throughout, and the coherent series of logical and 'believable' tasks presented, were expected to promote the feeling of being part of a community of practice during the delivery of the course. The tasks were designed to be somewhat indeterminate and ill-defined and to have more than one valid solution. Some were completed individually and some were based on teamwork. They were designed to encourage the use of observation by students of their peers' thinking through a solution and some negotiation within teams as to which of their solutions they were to recommend to the management of Team Detectors Limited. The activities were designed to promote the emergence of communities of practice by sustained exposure to the virtual enterprise and its problems, exchange of information, and negotiation of problem solutions, via e-mails, with the 'experts' at Team Detectors Limited.

The tasks were also designed wherever possible to make students aware of the multiple viewpoints that can be applied to most practical manufacturing systems problems. For example, in the ergonomics exercise students took the role and viewpoint of a manufacturing engineer investigating the problem but also had to keep in mind the attitude of the union and safety representatives to the problem. Further, the desires of the Manufacturing Manager with respect to efficiency and costs had to be considered. Finally, in reviewing the video of the operator carrying out the ergonomically problematic operation they were also immersed in the point of view of the operator herself. Students had to balance these multiple perspectives on the problem when designing and evaluating their solution.

Another novel feature incorporated into the intervention, to increase the fidelity of the immersive scenario, was the integrated use of several professional engineering software packages typical of those that graduates would be expected to use in the workplace. For example the ErgoEASE® program was used to perform the ergonomic analysis. This program allows students to input the results of a detailed movement and posture analysis, together with general task parameters such as task cycle time, to analyse a production operation and produce a range of reports on its ergonomic safety. The discrete-event simulation package Arena®, from Rockwell Software Incorporated, was used to build models and run simulations of the production processes and Preactor®, a software suite designed to replace manual planning boards using a Gantt chart/spreadsheet style interface, was used to carry out finite capacity planning operations for customer orders.

## 5. DATA COLLECTION METHODS

Data was obtained over four iterations and five applications of the intervention. It was collected in accordance with the principles of the design-based research methodology adopted for the project. That is, information was gathered from multiple sources including student surveys and questionnaires, semi-structured interviews with students and the researcher's observations of students' interaction with, and reception of, the intervention. The data was used to assist in determining the extent to which the intervention design met its goals of increasing the levels of student motivation and engagement as compared to those levels indicated by student feedback and course ratings before the implementation of the intervention. Feedback from the data collected was used to modify, refine and expand the web site, the virtual enterprise narrative and realia, and the student tasks.

Table 2 is an example of one instrument used in the data collection process as a template to ensure that the discussions in the semi-structured interview sessions would provide responses from students that would cover all of the elements of the design that were being investigated.

In order to collect first-hand data on the reception and use of the intervention, and the students understanding of the topics and software tools, an observational technique - participant observation was used [26]. A feature of participant observation is the interaction between the observer and the students and it is a technique commonly used in educational research [27]. Observations are a valid qualitative research data collection method when used and planned deliberately and recorded systematically [28].

In this study the researcher's role was as observer-participant as in the initial tutorial session for a particular task the researcher demonstrated the software to be used and described some typical problems and their solutions. For subsequent tutorial sessions on the same task the researcher took an observer role only. Field notes were used to record data and the notes were analysed immediately after the observation sessions.

## 6. RESULTS

In the two years prior to the first application of the intervention the average coursework mark was 63% and the average grade distribution was 21% A's, 37% B's and 39% C's. In the last two years of the intervention application the average coursework mark was 75.5% and the average grade distribution was 31% A's, 32 % B's and 34% C's. Following the implementation of the intervention the author and the other teaching staff involved in the manufacturing systems course have observed a more thoughtful and comprehensive approach by students to the problems presented to them. For example, prior to the intervention, the students' solution to the ergonomics problem— the redesign of the problematic workstation, was relatively naïve and short-sighted. The majority of the solutions offered, whilst generally solving the ergonomics issue, would, if implemented, cause severe production flow problems both upstream and downstream of the process. Post intervention the solutions have generally taken a wider, more integrated view of the problem with the solution fully integrated into the overall production flow.

The following data in this section are those obtained from the latest iteration of the intervention (July–October, 2008) and include details of the results parts A and B of a student questionnaire, the observations of the researcher of the student's interaction with the intervention and their team dynamics, and the results of semi-structured interviews with course members.

### 6.1 Questionnaires

The results of a student survey carried out to evaluate the interface with the virtual enterprise are shown in Table 3.

The results of the student survey carried out to

Table 2. Question Template for Semi-Structured Interviews

| Question | Purpose | Research Question Element/s | Situated Learning Element |
|---|---|---|---|
| The Team Detectors concept attempted to place the course topics into a realistic context. What did you think about the attempt? | To determine how the intervention modeled the 'real-world' of manufacturing. Authenticity. | Can delivery of complex non-quantitative topics be modified to improve student enthusiasm and engagement? | Authentic Context and 'real-world' relevance. |
| The Team Detectors concept attempted to make the assignment tasks realistic examples of what an engineer might do in the workplace including a certain level of uncertainty in the information provided. What did you think about these attempts? | To probe if problems presented were authentic, and ill-defined to a suitable level of uncertainty, and offered multiple interpretations and solutions. | Can delivery of complex non-quantitative topics be modified to improve student capability to perceive theme as scientific and coherent bodies of knowledge? | Provide authentic activities of an ill-defined nature. |
| In tasks such as the layout, ergonomics and simulation tasks you were able to view the problems from the point of view of different members of the company.<br>Did these different views help in your understanding of the topics and the solutions' complexities? | To determine what points of view students adopted and if these students found the intervention helpful in understanding the topics. | | Provide multiple roles and perspectives. |
| In some of the tasks you worked in small teams. How did you feel about working in teams? | Utilisation of, and enthusiasm for, the opportunities to collaborate and reflect. | Can delivery of complex non-quantitative topics be modified to improve student enthusiasm and engagement? | Support collegial collaboration in the construction of knowledge.<br>Promote reflection. |
| What did you feel about the level of assistance provided by the company's representative, the lecturer? | Were opportunities to seek advice from 'experts' useful . | Can computer technology help in the delivery of complex non-quantitative topics | Provide access to expert examples of performance.<br>Provide coaching. |
| What did you think about the assessment being tied to each task and solution? | To examine opinions about the integration of assessment into tasks. | Can delivery of complex non-quantitative topics be modified to improve student capability to perceive theme as scientific and coherent bodies of knowledge? | Provide for integrated assessment. |
| Do you have any other comments about the virtual factory. | To gather other relevant opinions not expressed in previous responses. | – | – |

Table 3. Student Questionnaire, Part A

| Question (N = 52) | Strongly Agree (No.) (%) | Agree (No.) (%) | Undecided (No.) (%) | Disagree (No.) (%) | Strongly Disagree (No.) (%) |
|---|---|---|---|---|---|
| The Team Detectors Ltd. web pages were uncluttered and clear | 7 (16) | 26 (60) | 6 (14) | 2 (5) | 2 (5) |
| The hyperlinks on the web pages are clearly identifiable | 6 (14) | 22 (51) | 9 (21) | 4 (9) | 2 (5) |
| Important information on the assignments was easy to find | 8 (19) | 18 (42) | 14 (33) | 3 (7) | 0 (0) |
| Navigating around the Team Detectors site was easy | 11 (26) | 22 (51) | 8 (19) | 1 (2) | 1 (2) |
| The instructions in the Manager's memo were easy to interpret | 6 (14) | 28 (65) | 5 (12) | 4 (9) | 0 (0) |
| I had, or could obtain, all the resources needed for the task | 12 (28) | 23 (53) | 5 (12) | 3 (7) | 0 (0) |

Table 4. Student Questionnaire, part B

| Question (N = 52) | Strongly Agree (No.) (%) | Agree (No.) (%) | Undecided (No.) (%) | Disagree (No.) (%) | Strongly Disagree (No.) (%) |
|---|---|---|---|---|---|
| The use of a real industry scenario added interest to the tasks. | 13 (30) | 18 (42) | 6 (14) | 4 (10) | 2 (5) |
| The use of a real industry scenario added relevancy to the tasks. | 14 (33) | 19 (44) | 6 (14) | 2 (5) | 2 (5) |
| I became more interested in the course material because of the company scenario. | 10 (23) | 17 (40) | 9 (21) | 5 (12) | 2 (5) |
| The Team detectors concept helped in understanding how the physical components of a manufacturing plant and the types of organisational systems used in it work together, e.g. machine tools and scheduling. | 9 (21) | 24 (56) | 5 (12) | 5 (12) | 0 (0) |
| The Team Detectors concept enhanced my understanding of the lecture material. | 7 (16) | 19 (44) | 9 (21) | 4 (9) | 4 (9) |
| I would recommend that the concept of industry based scenarios be extended to other engineering topics. | 16 (37) | 15 (35) | 7 (14) | 1 (2) | 3 (7) |

evaluate the assistance provided by iteration number four of the intervention are [A1]shown in Table 4.

*6.2 Observation*

Observation of students was carried out in two parts. In the first, observations were made of students' reception of, and interaction with, the virtual enterprise web site. Students accepted, but were not particularly impressed with, the pilot design since the site was quite basic and the Home Page consisted mainly of a plan view of the plant. In later iterations the Team Detector's web site was substantially increased in size and its theme and design were more closely allied with a typical commercial site with the emphasis on the product. Students had no difficulty, when working with this site, in suspending disbelief and accepting it as a bona fide commercial web site.

The other part of the observation programme was to observe the interaction of students, both individually with the web site, and collegially in teams. The aim was to assess the extent to which students' learning activities were influenced by peers and how far they considered themselves to be, and behaved like, members of a community of practice. This characteristic was assessed by the observer by noting the level of immersion in the tasks exhibited by students, by their references to past and to future tasks and, of course, in their dialogues with peers.

For example, students working on the production scheduling tasks with the software application Preactor®, were observed to work in informal teams (of two generally) to approach the problem and assist each other with applying the software, an example of distributed cognition. There were many solutions to the problem of scheduling a mix of different products and quantities through Team Detector's production process in a fashion that would produce as many on-time deliveries as possible. Selecting the best combination of products, customer orders and production schedules, at the same time as ensuring that the parameters in the software database were correct, lead to some very animated students who became extremely involved in the problem and quite concerned if one of their customers appeared likely to receive a late delivery. Comments such as *'I have to deliver this detector by the due date or I will be in trouble'* indicated some level of identification with the company's virtual staff and COP participation.

*6.3 Interviews*

Over the course of the various iterations of the virtual enterprise student response, as garnered in semi-structured interview sessions, was positive. The comments reproduced later in this article are samples of the feedback received. These comments are from 20 randomly selected students, being 25% of the total course cohort in 2008. These students were generally enthusiastic about the Team Detectors virtual enterprise intervention. Eighteen respondents commenting favourably, whilst two were unimpressed.

## 7. SUMMARY

*7.1 Social learning theory*

The intervention which is the subject of this paper incorporated the four conditions, described by Bandura in his theory of Social Learning, that are required for the process of gaining new skills: attention, retention, reproduction and motivation.

Attention, by students, to the target skills and knowledge required was encouraged by the use of the immersive virtual enterprise and its surrounding narrative and, as students expressed it, an interest in seeing 'how it all works out':

> It definitely made the course more interesting.

> Yes, I thought Team Detectors was good it made a whole bunch of theories more interesting. It put an image in my head and helped me remember.

The targeted behaviour was also reinforced by the use of appropriate videos of domain experts at work and the information given to students, on request, by the virtual practitioners at Team Detectors Limited:

> It was cool, emailing the Factory Manager and getting a reply.

> The videos were good, of real people and problems. I was surprised how much the guys on the shop floor did [create and promote system improvements]. I thought they were all anti-company.

The retention of new material was encouraged by observing practitioners (via a range of relevant videos) dealing with similar problems to those given to students, thus allowing them to model similar behaviour. Retention was also promoted by the use of mental images provided by the 2D and 3D views of the virtual enterprise and its manufacturing facilities, photographs of the virtual staff within the company, and rehearsal of the desired behaviours by working through problem examples in class:

> Team Detectors was good. Listening to somebody just talk about topics it is one thing but seeing it in use like at a real company or a virtual one like Team Detectors is much better.

Reproduction of the desired new knowledge was promoted by the completion of the course tasks, some of which required more than one iteration to achieve a satisfactory solution:

> The way the jobs all interconnected, that was good.

Finally, Bandura's fourth condition— motivation, was generated both by the conventional factors of grade rewards for good work and by the competition that arose between team members, and between teams, to provide the best solution in the class and an expressed desire to 'help the company':

> I liked the simulations, it was hands on. It added a lot of interest to me.

Although not all students were involved:

> Involved? Not really. It might just be my approach I just look at the assignment and do what is wanted.

*7.2 Communities of practice*

The intervention was also designed to incorporate Lave and Wenger's complimentary concept of Communities of Practice. The principles of which concept are that knowledge should be presented within an authentic context and that to be effective learning needs to take place within an environment of social interaction and collaboration. These principles were incorporated into the intervention by presenting the course material via the narrative-rich and contextually accurate virtual enterprise.

> I though the Detectors company was a real company for a long time.

> I liked doing the, sort of, jobs for Team Detectors.

Communities of practice were also fostered by the collaborative use of teams in which the students were able to observe their team members applying their individual skills and knowledge to solving a common problem.

> Yes, the teams helped, we discussed the topics and then knew more.

> We had some issues and disagreements with versions of the [*plant*] layout. But we worked it out with discussions.

Not all students were convinced:

> If you don't mind me saying so, I didn't pay that much attention to teams to be honest.

*7.3 Situated learning*

These complimentary theories were applied within a situated learning framework as suggested by Lave and Wenger [15]. The characteristic elements that should be present in such a situated learning framework are described by Herrington [29] as:

- An authentic context that reflects the way the knowledge will be used in real life.
- Authentic and ill-defined activities which have real-world relevance.
- Access to the observation of expert performances.
- Exploration of multiple roles and perspectives.
- The opportunity for users to collaborate and articulate argument/discussion
- Reflection on personal learning.
- Authentic assessment seamlessly integrated with the activities.

A selection of the comments from the semi-structured interviews, as they relate to the situated learning elements, are given below:

*On the provision of an authentic context*

> Well, really, I thought it was a real company. Wow, it was very realistic.

*On the provision of authentic activities*

Note that some students interestingly used the word 'job' rather than 'question' or 'problem' when commenting on tasks suggesting an encouraging amount of immersion in their role as consultant to Team Detectors Limited:

> The Team Detectors concept was good and the exercises were interesting. It's a bit like having a job.

*On access to the observation of expert performances*

> The video clips of companies operating were good, not too long.

> The guy with the glasses was good for lean [Factory Manager at electrical goods manufacturer] and the little lady [operator] explained it good.

> Those guys at the lean place [Gentrac] were really

> enthusiastic, I liked them, I don't think it was for the cameras.

*On multiple roles and perspectives*

> The different point of view really came out in the video [of a whiteware manufacturer] for and against 'lean', eh. The manager thought everything was sweet but the guys [operators] were really brassed off, you could tell.
>
> In the ergonomics job you could see where the manager and the operator were coming from, they both had pros and cons.

*On opportunity to collaborate in teams and articulate argument/discussion*

> Yes, I like to do assignments in a team as long as it is a good team.
>
> I like teamwork, especially if you're with the right team, it makes you more productive and you all come up with way more ideas. By year three second semester you recognise pretty much everyone in the class but you don't know them. In a team it gets quite nice to meet with the others.
>
> Working in the teams helped us to learn more about the topic.
>
> Talking about the software and the output in the team helped a lot. We had a good group, very together.

Two students made valid points about the practicalities of student collaboration:

> Sometimes, though not often, some people stop contributing if they think you have got more marks than them.
>
> I'm pretty easy about teamwork. I can take it or leave it. We all end up collaborating anyway.

*On opportunities for reflection*

> The task notes, they encouraged you to read your course notes even the ones not for the assignment.

*On authentic and integrated assessment*

> What I liked was the way the tasks joined together. That made them make sense, yes . . . . much better than ordinary lecture test questions.
>
> The jobs joined together, like a story. Also I liked the often, little assessments.

Whilst one student commented:

> The assignments seemed to be more about learning the computer programs than course material.

### *7.4 Design-based research*

A design-based research methodology was used in the design development and evaluation of the intervention. A starting point in the process of developing this design-based research study is to define a workable process [30] as a set of systematic steps to be followed during a micro-cycle (within a semester's course) as well as the total research programme macro-cycle. These steps were:

1. Crafting the Design: Developing the overall framework for the entire course including the syllabus, course schedule, learning goals, multimedia materials and simulations.
2. Testing the Design: The intervention was implemented while the course was in progress. The concept was tested to ensure that the computer technology and software were working as required. Data was collected using questionnaires and student observation.
3. Analysing the Data: Feedback from the evaluation survey used to provide information about the perceived value of the intervention in encouraging engagement and motivation and a grasp of the open-ended and integrated nature of the domain. Comments were submitted by students who completed the evaluations which provided insight into the nature of any technical problems or misunderstandings about the multimedia and other software content.
4. Build Theory: The data was analysed to determine if there was evidence to support revision or extension of the theories applied during the design of the intervention.
5. Revise and Retest: The design was revised and retested to improve the intervention and also to continue testing theory until, as van den Akker [31] says, 'a satisfying balance between ideals and realisation had been achieved'.

## 8. CONCLUSIONS

The research question to be addressed in this research was:

> Can the current[2] delivery of complex non-quantitative topics such as manufacturing systems be modified to increase (a) student engagement, (b) enthusiasm and (c) students' capability to perceive them as coherent and scientific bodies of knowledge?

These questions were to be addressed by the application of Bandura's Social Learning Theory and Lave and Wenger's Communities of Practice within the context of a situated learning framework.

The data collected during the research programme, from triangulated sources, indicated that the immersive multimedia teaching intervention was successful in meeting the research goals of improving the delivery of a course in a complex non-qualitative domain.

The conclusion can be drawn that the application of Bandura's social learning theory principles to the intervention ensured that the design of the intervention, with its use of teams, videos and advice from staff at Team Detectors, assisted

[2] In this context current refers to the teaching methods and student attitudes to the course prior to the commencement of the research programme.

students to learn practitioner behaviours, through observing and modelling others. Observation of the student teams indicated that the less able students in particular were assisted. A level of student engagement with the material was also promoted as indicated by the following student feedback:

> The videos and film gave a personal touch to the course that I haven't met before.

> You know, I really wanted to help her out [operator in ergonomics task Video], silly because it's only an exercise.

> It's weird. At home I kept thinking that if I have one more go at Arena I might get a better result, flow. It's a bit addictive.

These results were reflected also in the data from the student questionnaire with positive responses ('Strongly Agree' and 'Agree') of 72% to the question 'The use of a real industry scenario added interest to the tasks'. The negative response ('Disagree' and 'Strongly Disagree) was 15%. For the question 'I became more interested in the course material because of the company scenario' the positive response was 63% and the negative response was 17%.

Lave and Wenger's communities of practice concept [15], and the situated learning framework within which it was applied, appeared to be a successful approach, increasing the level of motivation brought to the course by students and assisting them to grasp the integrated nature of the topics covered. The use of tasks with authentic content in a realistic context also demonstrated to students the inevitable open-ended and indeterminate nature of many of the problems encountered by manufacturing Systems practitioners in the workplace

However, one conclusion is that it was difficult to ascertain to what extent *true* communities of learning, as described by Lave and Wenger, had been effectively established. Certainly students interacted with the virtual staff at Team Detectors Limited and took future tasks and the well-being of the organisation into account in the discussions and solutions. More so than one would expect from a typical co-operative or team-based learning intervention. More research is required in this area with this intervention to establish parameters whereby their existence could be more clearly determined.

Nevertheless, the problem of low levels of enthusiasm exhibited by students studying this ill-defined and indeterminate domain was addressed by the situated learning approach. The consistent use of Team Detectors Limited enabled the course to present to students an integrated series of tasks with 'authentic' content which had a logical reason for their existence. They were not the usual 'end-of-chapter' de-contextualised problems. The provision of an authentic context, and the use of authentic content in the cognitively challenging tasks to be completed, raised the level of situational interest, a prime element in promoting increased levels of enthusiasm and motivation in students [32–35].

The following sample quotes from students in the semi-structured interviews indicated the success of the attempt to increase levels of enthusiasm:

> With the high-level of internal assessment it helped to make it interesting. I was more motivated to play with the software we did.

> Yes it definitely motivated you (the tasks/assessments).

The data from the student questionnaire indicated a positive responses ('Strongly Agree' and 'Agree') of 77% to the question 'The use of a real industry scenario added relevancy to the tasks.' The negative response ('Disagree' and 'Strongly Disagree) was 10%. Student attitude to relevancy is an indicator of their level of enthusiasm. Students were keen to say in interviews that they were not enthusiastic or motivated to attempt, at anything other than a token level, tasks or assignments that they felt were 'made up' or 'make-work' exercises.

### *8.1 Students' capability to perceive course as coherent and scientific bodies of knowledge?*

This phrase in the research question refers to the pre-intervention feedback from students that the manufacturing systems course appeared to be a series of topics only loosely connected. They considered them 'unscientific' as a result of problems often being ill-defined, the common use of 'heuristics' or 'rules of thumb' to find solutions to problems and the indeterminate nature of many of problems they encountered where it was not possible to determine which of their answers was the best or optimum one. These features did not appeal to engineering students used to well-defined topics and exact solutions based upon fixed physical laws.

The common problem of coherence, of the students not understanding how the systems topics meshed together, has been tackled by applying authentic tasks in an authentic context with the tasks linked in a logical sequence which make technical sense. The topic material covered mapped the 'story' being told (throughout the duration of the course) about the virtual enterprise; from establishing a new plant layout through to providing finished products, on time, to the customers. The concept of integration was reinforced by the tasks, which also mapped the narrative and topic presentation. Biggs [36] suggests that a demonstrated connection between course topics also increases levels of enthusiasm and motivation. A sample interview comment on this issue was:

> The way the jobs all interconnected, that was good.

The problem of the acceptance of indeterminacy and heuristic methods as valid were tackled by the appropriate design of a series of well-connected tasks presented to the students. The data given to students had a designed-in level of indeterminacy and the specified outputs or results were also left somewhat open. For example, in determining the throughput of their manufacturing system in an Arena® simulation the students were required to attempt to achieve a reasonable output but no specific figure was given as a target.

The 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 enthusiasm since students are more enthusiastic about 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 is also a motivator:

> The task of the facility layout was good as it was hard to know if you should treat it as a typical university project or think outside the box and have a risk of not doing what was wanted.

> I thought that the assignment data was not too wordy. We had to think about what was relevant, like in a real job.

Student feedback from questionnaires, observation and semi-structured interviews indicated that the immersive, multimedia intervention based upon a virtual manufacturing enterprise did indeed increase levels of student engagement and enthusiasm for the course. It promoted an increased awareness of the integrated nature of the varied topics in the manufacturing systems domain when compared with the situation prior to the adoption of the intervention. Student feedback on the university standard assessment form for the courses is now overwhelmingly positive and the approval score (out of 10) has risen from 3.7 to 7.0.

The use of the design based research methodology in the research programme successfully allowed the design to implement a unique educational intervention in a realistic classroom setting rather than in an artificially controlled randomised trial experiment. It also allowed the design to collect data from several sources and refine the design in an interactive manner as experience provided new insights. A further benefit of the methodology was found to be the insight and experience it gave of the intervention/educational design process itself.

## 9. FUTURE DEVELOPMENTS

Further research is planned utilising the virtual enterprise.

The first area to be investigated will be determine whether, or not, exposure to this teaching intervention has a positive effect upon student's self-efficacy as compared to other, demographically similar, students who do not take the manufacturing systems course. Self-efficacy was described by Bandura [37] as an important contribution to career development and, for engineering students, an important indicator of a student's likelihood of success in their studies. This investigation will require the development of a reliable self-efficacy instrument and the collection of qualitative data for analysis.

Also, as discussed in the Conclusions section of this paper, further work is required into techniques and materials which will foster the development of *true*, rather than pseudo, communities of practice in undergraduate engineering courses and the development of a more systematic method of establishing and measuring teamworking skills.

We wish to also investigate if the use of ill-defined problems with multiple, valid solutions assist in encouraging students to move from what Perry [38], in his research on students' levels of intellectual development, called a dualistic, one solution, black and white, or right versus wrong view of the world, to a relativistic view which allows for multiple solutions, uncertainty and shades of grey. The importance of studies on epistemological positions such as this for engineering educators is that it posits that students will not be able to understand, or answer, open-ended problems which require a stage of intellectual development beyond that which they currently possess. Studies may reveal if the level of uncertainty in the current Team Detector tasks are appropriate for a typical students' level of intellectual development as measured on the Perry scale.

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