Using 3D Modelling and Dynamic Thermal Simulation Software Tools to Facilitate Student Understanding of Complex Principles in 'Passive' Building Design – An Experiential Learning Approach

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Abstract

Students today are much more PC and IT literate than their counterparts of five or ten years ago. The huge increase in Internet usage, PC's in schools and interactive game play are surely a contributory factor in this. Students enjoy using IT, both during leisure and their studies. The purpose of this innovative introduction to student studies was to develop in students an enthusiasm for working with others and team building whilst developing, analysing and understanding 'real world' projects having a strong IT link and incorporating those projects within a 3-D building modelling and simulation software tool. To facilitate student understanding, the assignment was developed around David Kolb's 4 stage learning styles model of 'concrete experience', 'observation / reflection', 'generalisation / conceptualisation' and 'experimentation / integration'. Working as teams, students created two simple case study buildings and, by carrying out interactive real-time 'what if' scenarios, determined how and why the materials used in the construction of buildings affect their thermal performance.

Introduction

> *Much of our traditional learning experience has led us to believe that we learn best by listening to experts. It has been found, however, that learning that results in increased self-awareness, changed behaviour, and the acquisition of new skills must actively engage the individual in the learning process. In particular, adults have been found to learn more effectively by doing or experiencing.*
> (Association of Research Libraries, 1996)

Adult learning specialist, David Kolb, has described the learning process as a four-phase cycle in which the learner: (1) does something concrete or has a particular learning experience (the 'Doing') that provides a basis for (2) the learner's observation and reflection on the experience and their own response to it (the 'Feedback'). These observations are then (3) assimilated into a conceptual framework or related to other concepts in the learner's previous experience and knowledge (the 'Digesting') from which implications for action can be derived, and (4) tested and applied in different situations (the 'Wanting') (Figure 1).

> *The adult learner assimilates useful information into their personal 'experience bank' against which future learning events will be compared and to which new concepts will be related. Unless what is learned can be applied to actual work or life situations the learning will not be effective or long lasting. People responsible for designing learning events should*

> *keep these phases in mind as they develop ways to help the learner understand and be able to use the new knowledge and/or skill.* (Association of Research Libraries, 1996)
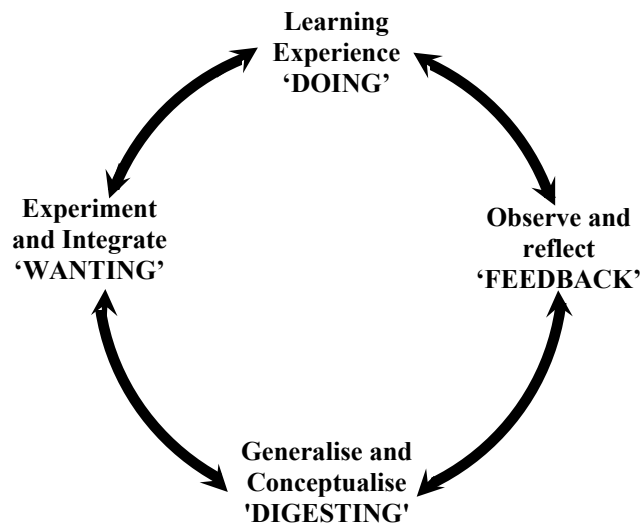

Figure 1: Learning Styles (Adapted from Kolb 1984 and Race 1994)

The concept of 'learning by doing' is not new and is generally accepted as one of the key mechanisms in which people achieve deep learning.

Unfortunately, a considerable problem with all construction disciplines is the fact that design teams cannot develop design concepts into real buildings. The majority carry out design calculations as a paper-based exercise, via a spreadsheet or simple computer software analysis. They are not able to see the physical results of their calculations as this would mean a real building would have to be constructed, monitored and analysed over at least a 12-month period in order to confirm or contradict the calculations. In these terms the requirement to learn by doing cannot be achieved. In other disciplines, such as mechanical and electrical engineering, where end products are designed for consumption in the mass market, students have the ability to build full-scale mock-ups to assess their calculations and to assist in performance analysis. The data gathered from this process is then used to modify their design to optimise performance prior to mass production. The costs involved in building these prototypes are deemed minimal compared to those saved via optimised manufacturing methods, visual design, customer satisfaction and final product cost.

In the construction industry, however, building a full-scale model is simply not practical nor financially possible and the benefit from part scale models is only really useful for the visualisation of the final product in terms of its built form, surface rendering, daylighting performance, etc. The lack of ability to properly test each scheme is surely a contributory factor towards one third of construction clients being unhappy with the finished product after handover (Egan 1998).

In recent years, however, PC's have developed at such a pace that their processing speeds now allow the use of building design analysis tools that could only previously be used on large mainframe systems. These tools are able to create virtual buildings in a 3-D environment. It is possible to allocate real world physical properties to the building components and analyse the environmental performance of that building design.

Previous tools were only able to analyse a building's performance by incorporating many simplifying assumptions. The sizing of plant to control internal conditions can absorb some over estimation resulting from simplifying assumptions and still produce a functional design. However, such a procedure, when used to evaluate the effectiveness of passive solutions for control of internal conditions, can mask the potential benefit of important features.

Passive design is a process by which the natural environment outside buildings, and the conditioned environments to be created within them, are analysed in parallel with the ways in which the building envelope filters that climate and tempers the internal environment. Passive design works with these analyses and develops ideas/strategies for the design of whole buildings that have minimal reliance on mechanical plant.

The 'real life' modelling and simulation facilities offered by these 'building analysis' tools mentioned earlier opens up whole new areas for student teaching and learning across many disciplines. There are many examples that could be given to demonstrate the benefits of using computers to aid learning. This paper describes one such example

The Problem

Students of building construction need to have an understanding of many aspects of building design that lie outside their chosen career discipline. One such area covered at Salford is a level two module titled 'Services 2'. This module introduces the student to the need for environmental comfort within buildings, heat loss and heat gain calculations and passive design approaches among other things. Passive design is particularly stressed as many future construction projects will invariably be driven from a sustainable, low energy consumption aspect and tomorrow's project teams will need to have a sound understanding of the principles underpinning passive design. Some of these principles are however quite difficult to grasp due to their abstract nature and attempts to convey understanding via traditional delivery methods such as lectures and tutorial discussions have not been too successful in recent years. This was evidenced by exam results where questions relating to passive design concepts were either not attempted or answered poorly.

Possible Solutions

One solution is simply to do nothing apart from persevere with the traditional 'chalk and talk' lecture used with previous cohorts. This approach clearly does not involve any further expenditure in terms of money or other resources but, as noted earlier, does not produce deep learning in many students. Perhaps the ideal solution would be to build, monitor and modify full scale models of proposed buildings in a similar fashion to the methods employed by the mechanical and electrical engineers mentioned earlier. Of course this is quite obviously out of the question for many reasons.

However, the design, analysis and re-design of 'virtual' buildings within advanced simulation software does not pose such difficulties and allows the design team to carry out a multitude of 'what if?' scenarios without ever having to lay even so much as a brick.

When the Services 2 module was restructured a few years ago the module tutor investigated how passive design concepts might be analysed within a collaborative, group-based coursework. When the tutor later obtained funding to purchase a dynamic thermal analysis software tool, 'Tas', the passive theme and the design of the coursework became a clear option.

The Use of Instructional Technology in the Lecture Room

Many barriers exist in higher education to the adoption of instructional technology within the lecture room. Change in higher education has traditionally been slow as the anonymous quote, apparently from a frustrated instructional technologist, demonstrates:

> The pace of academe is perhaps best measured by the 25 years it took to get the overhead projectors out of the bowling alley and into the classroom
> (in Gilbert & Green, 1997, p. 25)

A recent survey by Beggs (1999) highlights many influencing factors and barriers to the adoption of Instructional Technology in the lecture room. Influencing factors for introduction include:

- A clear improvement in student learning has been previously demonstrated;
- There are clear advantages in its use compared to traditional approaches;
- The equipment needed is readily available;
- The technology is easy to use;
- The technology does not take long to learn to use.

Barriers to introduction included:

- A lack of time available to lecturers to learn and introduce the new technology;
- A lack of available/suitable technology.

Many of these factors became important concerns during the duration of this project. The available funds for the software only allowed the purchase of eight licenses in total. With an expected student cohort of over fifty and a preferred group size of four there was clearly going to be access problems. Also, the module tutor was aware that the software was not as 'user friendly' as he would have preferred and, despite the available help facilities that included audio/video tutorials, further guidance would be required.

It was therefore decided that the software tool alone would not be the sole method of explaining and facilitating the understanding of passive building design as it was appreciated that sole reliance on an untried software tool may create assessment difficulties if problems with the software materialised. This proposal is, however, innovative in that the use of dynamic building analysis software coupled with an interactive, case study scenario simulating a 'real world' problem has not been used within the School of Construction and Property Management before.

The Solution

The passive building design project was split into three separate tasks. An introduction set the scene and highlighted key concerns such as the 'Environment', 'Energy Conservation' and other 'Green' issues. Tasks 1 and 2 were individual student tasks requiring them to research various aspects of passive design. Task 3 was the collaborative part of the assessment. In this task student groups were asked to use the 'Tas' software package available on selected PC's in the TI room to analyse a simple building structure in terms of total space heat gains and peak internal summertime temperatures for various construction types.

Finally students were asked to reflect on and then discuss their findings in terms of perhaps the two most difficult of the passive design concepts to understand: 'time-lag' and 'decrement factor'.

The learning was incorporated within the main module assignment and was developed/structured around the adult learning theory of David Kolb (1984) i.e. 'Experiential Learning'. Kolb's approach was chosen because it is a learner-centred approach, it starts with the assertion that people learn best from experience i.e. *learning by doing* and learning occurs as a result of the learners active participation in structured activities.

Kolb's theory outlined four principle stages:

1. **Concrete Experience $\rightarrow$ Learning Experience 'DOING';**

2. **Reflective Observation $\rightarrow$ Observe and reflect 'FEEDBACK';**

3. **Abstract Conceptualisation $\rightarrow$ Generalise and Conceptualise 'DIGESTING';**

4. **Active Experimentation $\rightarrow$ Experiment and Integrate 'WANTING'.**

These four stages were described as an iterative process and were therefore illustrated as a 'learning cycle' as shown in Figure 1 earlier.

The project commenced by getting students to:

1. Familiarise themselves with the software, research key values for data input and to use the software to generate initial simulation runs and outputs (doing);
2. Review what was done, observe results and discuss why they occurred (feedback);
3. Interpret and analyse findings, identify trends and patterns and discuss applicable theory (digesting);
4. Plan the next activities, suggest modifications to the model and predict outcomes (wanting).

After completing this first cycle students then carried out further data refinement before inputting it into the model and completing more simulation runs (doing), review and observing results (feedback), etc. The learning cycle thus became an iterative process; at least this is what was expected. However, observation by the author of the various student groups suggests that not all of them followed the learning cycle as described. It became clear during interaction with the software programme that not all students/student groups were following the generally accepted clockwise rotation around Kolb's cycle from 1 to 4 and then repeating from 1 again. Often it would appear that students started at 1, reached 2 and then went straight back to 1 without really thinking about the results or discussing and planning what data needed changing to get the results they wanted. There was very much a feeling of a 'trial and error' approach in these situations. It became clear to the author that there were many paths around (or through) Kolb's cycle and further research was warranted (see later).

The Learning Process

The coursework brief was issued during week two (early October) of semester one. The coursework was discussed on two occasions during tutorial sessions to ensure students understood what was asked of them. After week six the module tutor arranged a number of software demonstrations in place of timetabled tutorial sessions as well as many individual/group demonstrations on a per request basis.

Individual/group sessions were in fact not so much tutor-led demonstrations but more interactive discussion and analysis sessions, in which the tutor set the scene, asked questions and assisted with the input of data to the software tool based on an agreed response to those questions from the student(s). Results produced were then discussed in the light of expectations from earlier discussions.

Evaluation

Pre- and post-evaluation surveys were carried out with the students by the module tutor in an attempt to quantify their understanding of key heat transfer and passive design concepts before and after the coursework was issued and submitted. The pre-assessment questionnaire asked students to comment upon any preparation they had carried out prior to the assessment. This was to ensure that those students who had taken it upon themselves to carry out any pre-studies for the Services 2 module were identified. It then asked them a series of seven 'short - answer' questions concerning key aspects of heat transfer and passive building design.

The post-assessment questionnaire, carried out approximately four weeks after the coursework was submitted for marking, once again asked students if they had carried out any preparation prior to answering the same 7 questions as the pre-assessment questionnaire. To reduce the chances of students remembering the sequence of questions asked from the pre-assessment test, this second set of questions were re-worded and rearranged in a different sequence to the first set. Further questions were asked at post-assessment to gain comments from the students on their perceptions of whether or not the Tas software had helped with their understanding of passive building design. The seven questions in the pre- and post-assessment questionnaires were marked on a scale from zero to five where zero equated to no answer or one that was completely wrong and five equated to a detailed (within the space allowed) and fundamentally correct response.

Summary of Findings
Pre-assessment
Prior to commencing the assignment most students commented, on the pre-assessment questionnaire, that they had carried out very little preparation. Pre-assessment students scored an average mark for the seven key assessment questions of 4 out of 35 with several marks of zero and the highest being 10! These marks were surprisingly low considering that the Environmental Science module in level 1 does cover 'basic heat transfer' and 'the building as a climate modifier' within two key parts of the syllabus. The low marks would tend to suggest that any learning achieved was mostly of a 'shallow' nature necessary for passing the module end exam and not the 'deep' level learning that suggests understanding has been achieved, however the high number of direct entry students would also affect this assessment.

Post-assessment
Four weeks after submission of the coursework students were assessed once again, achieving an average mark of 16 out of 35 with a minimum of just 2½ and a maximum of 22. Although these average marks are four times better than the pre-assessment average the module tutor was still disappointed and had hoped for considerably higher marks. However, when the post-assessment questionnaires were analysed for student feedback on the quality of the learning experienced by interacting with the software tool comments were found to be positive on the whole (see tables 1 and 2).

Analysis of Results and Student Feedback
The work of Jarvis (1995 cited in Smith 2001) attempts to illustrate that there are a number of reactions to the learning situation to which a learner is exposed. Jarvis used Kolb's model with several different adult groups and asked them to explore it based on their own experience of learning. Based on the feedback from those groups he developed a model that illustrated different routes through the learning experience. Jarvis' analysis of the feedback lead him to suggest that some of these routes are 'non-learning' routes, some 'non-reflective' learning, and some are 'reflective' learning. The diagram below (Figure 2) attempts to illustrate the many routes through Kolb's cycle available to the learner.
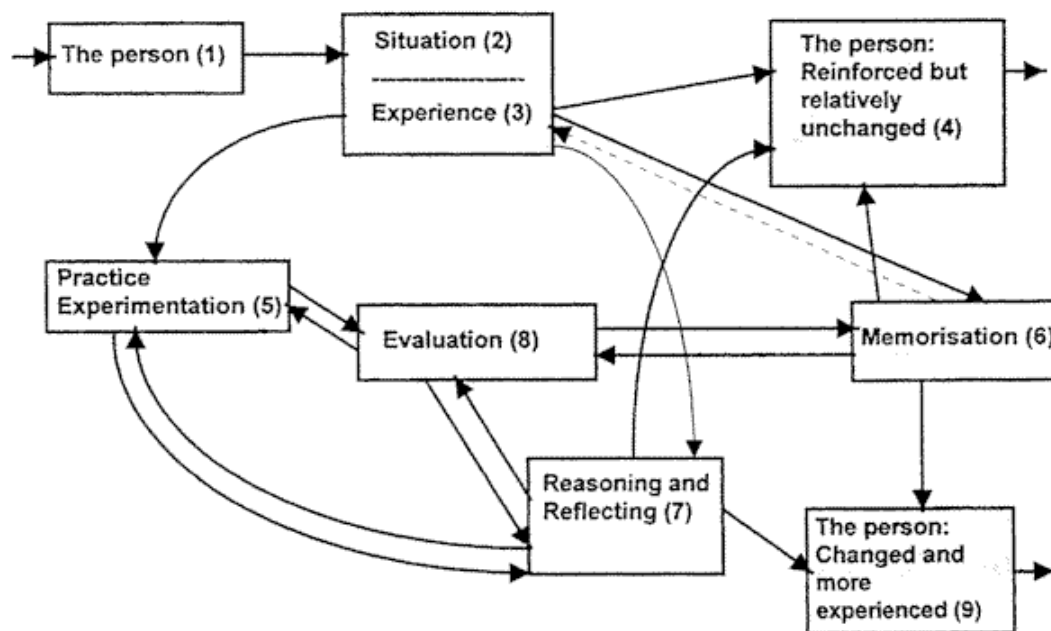
Figure 2: Modified Kolb Cycle (adapted from Jarvis 1994 cited in Smith 2001)

Jarvis offers descriptions of a number of routes through the model as follows:

Non-Learning:
- **Presumption** (boxes 1-4). This is where people interact through patterned behaviour. Saying hello etc;
- **Non-consideration** (1-4). Here the person does not respond to a potential learning situation;
- **Rejection** (boxes 1-3 to 7 to 9).

Non-Reflective:
- **Pre-conscious** (boxes 1-3 to 6 to either 4 or 9). This form occurs to every person as a result of having experiences in daily living that are not really thought about. Skimming across the surface;
- **Practice** (boxes 1-3 to 5 to 8 to 6 to either 4 or 9). Traditionally this has been restricted to things like training for a manual occupation or acquiring particular physical skills. It may also refer to the acquisition of language itself;
- **Memorization** (boxes 1-3 to 6 and possibly 8 to 6 and then either to 4 or 9).

Reflective Learning:
- **Contemplation** (boxes 1-3 to 7 to 8 to 6 to 9). Here the person considers it and makes an intellectual decision about it;
- **Reflective practice** (boxes 1-3 (to 5) to 7 to 5 to 6 to 9). This is close to what Schön describes as reflection on and in action;

- **Experiential learning** (boxes 1-3 to 7 to 5 to 7 to 8 to 6 to 9). The way in which pragmatic knowledge may be learned.

Adapted from Smith (2001)

This project attempted to make students follow the reflective learning routes through the cycle but observation and the post-assessment survey suggests not all did.

Table 1: Summary of Yes/No Responses to Various Questions
(NB - not all boxes were checked by each student)

Question	Yes	No
Was the software user friendly?	9	7
Did the user manual and tutor demonstrations help?	14	0
Did the software help with your understanding of any of the concepts and processes covered by the coursework?	9	3
Did the 'inside/outside temperature versus time' graphical representations assist in any way?	10	1

Table 2: Selection of Comments from Individual Post-assessment Questionnaires and the Mark Scored (NB: Some very long comments have been summarised)

Sample comments	Post Assessment score
'Useful when you understood how it works but difficult to understand all aspects of the software'	2½
'Simply laid out/good graphics/easy to read'. 'Demos by lecturer and software tutorials both useful'. 'Graphs helped show decrement factor and time-lag' & how different materials alter building envelope performance'	15½
'Wide range of materials and weather records available'. 'Easily readable and understandable graphs'. 'Advanced nature of software can be confusing to beginners'. 'Few computers had software loaded'. 'Graphs were quickly processed and project did not take too long to complete'. 'Time-lag and decrement factors could be clearly seen on the graphs for each building construction variation and showed significant differences'.	22
'Tas is a very complicated package and all available help was needed'. 'The graphs help me understand'.	3
'Liked using the technology'. 'Liked the end results (graphs)'. 'Took a long time to grasp'. 'Very complex'.	10
'Liked the visual diagrams of temperature differences rather than just figures and text'. 'Easy input of most of the data'. 'Took a long	

time to be explained'. 'Would have taken a lot longer to understand if tutor had not carried out demo's'.	16½

However, it is also true to say that those students who persevered with the software did gain a reasonable understanding of the basic tool. The majority of students commented that they found the user manual and tutor support very useful and many would have struggled without this help. Most students commented that they felt the software had been beneficial to their understanding of the key terms and concepts covered by the coursework brief. Almost all students stated that they found the visual representation of indoor air temperature versus time of day as a very helpful tool in their understanding of the two concepts of 'time-lag' and 'decrement factor'. However, it has also to be stated that several of the very same students who stated that the software and visual representations had helped them scored very poorly in the marked assessment!

The increase in questionnaire scores from an average of 4 marks to one of 16 marks suggests that there may well have been an increase in understanding of how buildings interact with their external and internal environments. However further assessment at say 6 month and 12-month intervals would perhaps demonstrate whether the project has fostered deep learning within students.

Initial difficulties with software and hardware coupled with the perceived complexity of the software itself did not encourage student groups to work together, discuss or reflect on their findings. In fact many of the more keen students decided to work by themselves on the project due the indifference of some of their fellow group members when they realised a significant level of input was required from them.
Overall it does appear that a significant number of the students who took an active part in the module felt they had enhanced their IT skills and many requested that more industry standard software be introduced to the undergraduate taught programmes.

It is felt that those students who did attempt to work together as a group enhanced their problem solving techniques though the module tutor mostly drove this when he ran the group demonstration sessions for the Tas software.

Recommendations for the Future
Introducing the Tas software programme to a module assessment mechanism proved to be difficult and time consuming though feedback from students who commented within the post-assessment questionnaire was mostly positive. It is intended to refine the assessment in the light of experience and student feedback for use in the Services 2 module in October 2003. However, for those considering introducing an industry standard software tool to undergraduate teaching, you are advised to consider the following recommendations:

- Ensure that module tutors and technician staff are completely familiar with the hardware requirements for their software tool. This requirement is considered as most important by technician staff in particular;

- Ensure that tutors and technicians have received training or are already familiar with the installation and use of the software tool;
- Ensure the tool is as user friendly as possible. Do not just rely on the guidance and help files provided by the software supplier. It is a good idea to produce a user guide for students;
- Test the software thoroughly on the machines that students will eventually be using. Try out the assessment as described to students to ensure that it is physically achievable in the time allowed;
- Ensure any conflicts with dongle security protection, screen resolutions, audio sound cards etc. are resolved long before students need to use the software;
- Consider providing dedicated terminals for sole use with the software tool if required system configurations would affect other software on the PC;
- Consider reserving/closing 'open-access' facilities for one or two hours per week in the early stages of the project to allow student groups' unrestricted access and to minimise distraction;
- Use reserved time slots to provide large group demonstrations via projector screens to avoid time consuming 'one-on-one' sessions;
- Ensure support technicians have been allocated sufficient time within their workload allocations to fully assist the project.

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