Problem Based Learning for the Design Process

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Abstract

The transformation of the communication, documentation and delivery of an engineering design subject is described and analysed in this paper. The subject, directed to 3rd year environmental engineering students at the University of Melbourne, has been given using a problem based learning approach for a number of years. The growth in class sizes lead to a number of teaching problems that were resolved by using a specially configured web site to facilitate a number of different communication and documentation processes used by students in the learning process. Web publishing by individual students and small groups was a key element in allowing students to share their ideas and resources in solving a substantial sized engineering design problem. An asynchronous web conference was used extensively in communication between class members and staff, largely replacing e-mails for electronic communication. Students wrote reflective diaries at 5 different stages of the 12-week subject. These have been analysed to gain an understanding of how student's expectations, understanding and feelings about the subject changed during the project. Delivery of the subject making extensive use of the Internet has been a positive experience for both staff and students.

Keywords

Problem based learning, Design, Engineering, Internet, Reflective diary, Education

Introduction

Design, or the synthesis of technical and non-technical information to solve industry and community problems, or meet their needs, is a fundamental activity of engineering professionals. Since for most problems there are several competing and alternative solutions, which require a combination of creative and analytical thinking, it is a subject that is almost always taught in some description in engineering courses. Simon (1996) sees the province of design as lying on the interface between the natural laws that govern the environment and the natural laws that govern the internal behaviour of an artefact. The proper study of this interface and the education of students in the process of design are central to the professional responsibilities of schools that train people for the professions, whether they be in engineering, medicine, law or commerce. Most students who study engineering spend most of their school and university lives analysing situations and are consequently very good at stipulating the *answer* to a certain set of circumstances. Indeed, it is people that are good at analytical activities that are attracted to engineering courses. However, for these people to perform effectively as professional engineers, they must also develop their creative abilities that may not come naturally to provide effective solutions to problems. Another aspect constraining learning of design is often the full range of knowledge to solve the problem is not readily available and thus the solution will only be available to those people who can marshal that knowledge through personal investigation or construction in multi-disciplinary teams.

Motivating a whole class to work and achieve

Finding the solution to the problem of motivating a group of people with disparate skills, aspirations and academic abilities to work consistently towards and eventually achieve a goal is a difficult task for tertiary teachers. No doubt it is not a new problem! The approach taken in my teaching and described in this paper is one where students are confronted with a problem that is much larger than they have ever faced before. On the surface it seems to have an apparent solution, but on closer inspection is found to be complex and even overwhelming or daunting. Having been posed with the problem, a carefully designed schedule of activities is presented to students, with an understanding that the staff will lead them through the activities and accomplish a solution.

Problem Based Learning Application

After the fundamentals of engineering design techniques have been learnt by the students, the environmental engineering course designers at the University of Melbourne have chosen to use Problem Based Learning to enable students to refine their skills in the design process. Glasgow (1997, p41) defines two educational objectives of Problem Based Learning: the acquisition of a body of knowledge related to a problem and the development and application of problem solving and reasoning skills. In the subject discussed in this paper, I am more interested in the second objective of development of the process of problem solving. In order to do this a project with following characteristics is chosen, with the project providing a group of people with a substantial size design problem, that:

- is within their general discipline area,
- has a range of creative solutions,
- can readily have the design skills applied to it in a controlled manner, and
- allows a range of group and individual activities so those students can develop their problem solving skills.

It differs from most other examples of Problem Based Learning in the University of Melbourne in that there is a concentration on refining the methodology of solving the problem rather than learning theory or practice by solving the problem. It also differs in the size of problem typically treated in undergraduate courses. The problem chosen is intended to be solved over 12 weeks and several hundred person-hours work.

How we got here.

What worked in a paper based system

The subject discussed in this paper is studied by 3rd year environmental engineering students and is conducted with a total student time input of about 100 hours with less than 20 hours face to face contact with staff. It is the second of three engineering design subjects. The three subjects are sequenced such that in the first subject, the students learn the fundamentals of design and creative thinking.

The subject matter is described in Samuel and Weir (1997). The second subject, discussed in this paper, uses a substantial project conducted over 12 weeks. Each week the students are lead through a particular phase of the design process. Substantial levels of class and group collaboration are required, though the students eventually write individual reports. In the final subject, groups of students investigate a substantial problem over a period of two weeks intensive work. The structure used for the problem solving is outlined in Figure 1. While student numbers were small the paper-based system was effective. Resources such as articles found by the students that related to the problem were easily shared by the students by storing them

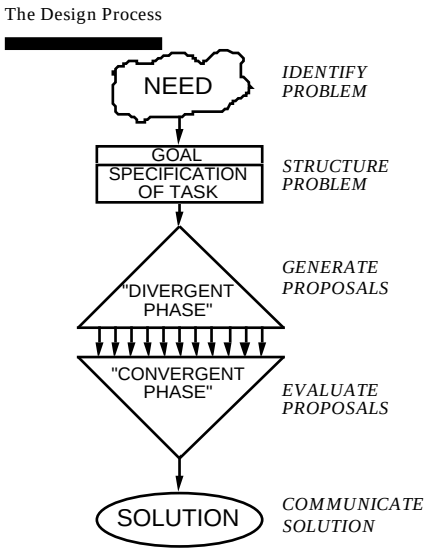

Figure 1. The Design Process (Samuel and Weir, 1997)

Problems encountered with paper based systems - student perspective

As student numbers grew (>20) the traditional system developed a number of problems. These included;

- Resources stored in the class file were removed for copying and not replaced.
- An indexing system for resources failed when they were not refiled in the correct locations.

- An increase in the level of flexibility in courses undertaken by students and part-time work resulted in increasing problems in students finding times to meet for group work.
- The larger number of ideas generated was not effectively utilised because the students were unable to access the ideas.
- Finally, from the student motivational point of view, some students did not feel a significant amount of achievement in a subject where, for the most part, the basic concepts had been learnt the previous year.

Problems encountered - instructional perspective

The sequential nature of the subject, where student work from one week was used as a direct input for the next week meant that the time available for assessment and criticism of the material was at a premium in the paper based subject. When work was critiqued and returned to the file for class use, almost invariably the material was misplaced, removed or damaged leading to staff frustration. The odd meeting times of the various groups meant that time to consult with staff was limited and questions went unanswered or were not addressed in a timely fashion.

Specification for a better methodology

As a result of the above-mentioned problems, a specification for a better system arose. The main aspects of the system were twofold: a better system of document management and a better system of communication between students at all levels (individuals, groups, the whole class) and with staff. It was perceived that the overall framework of the subject and the project-based approach was effective with the small classes and could be made effective again if these two key aspects could be addressed. At the end of 1998, a new service in the University of Melbourne (WebRAFT: http://webraft.its.unimelb.edu.au/) was reported by Knott et.al. (1998) which appeared to have many of the characteristics that would allow me to implement a better method at minimal cost in terms of time, new skills required and infrastructure.

The Advent of WebRAFT

WebRAFT, described in detail in the documentation available at http://webraft.its.unimelb.edu.au/ has the following main features of significance to my teaching of the design class:

- An easily accessed server that allowed publishing of static HTML documents by staff, groups of students and individual students.

- A means of easily allocating students to groups that had their own publishing area and access rights.
- A directory structure that was automatically available and was linked to the University student records system.
- A security system that allowed students to submit work for assessment to the server in the knowledge that they were the only ones that could alter the file, but allowed others to view their work if required.
- An asynchronous web based conferencing system to allow student and staff communication.
- An archival system that allowed CD images to be created
- A search engine that will search all documents on the site.

The Implementation of Design Teaching on WebRAFT

This section describes the main features of the subject implementation. A number of aspects of the site are available publicly on the Internet and these can be accessed at http://webraft.its.unimelb.edu.au/421322/pub/. The main areas of the web site and the way people interact with them are outlined in Table 1, while the various components of the areas are discussed in more detail in the remainder of this section.

Staff Centred Inputs

Brief

The Brief is a short description of the problem that the students will have to solve, plus a limited amount of background material. It is couched in terms of the students being consultants to a client. The staff take the role of the client in the class when necessary. The problem chosen is different each year and is chosen to reflect a real problem and one that allows for a range of solutions that can be analysed within the scope of the students' pre-existing or easily acquired knowledge. It is largely delivered by static HTML pages and a class face-to-face description of the topic. A typical problem, used in 1999, is outlined here.

> *"Background:*
> *It is the summer of 1999/2000. A severe bushfire has burnt over 80% of the catchments used for Melbourne's water supply. It is known that this will affect the hydrology of the water supply because of the variation in evapotranspiration of the regenerating forest compared to the mature forest that it replaces. At some stage there is likely to be a much lower yield of water to the reservoirs leading to the risk of water shortages in Melbourne.*

Proposal:
The State Government has commissioned you as consultants to propose a scheme of soft and/or hard engineering solutions to minimise the risk of water shortages for residents and industry over the next twenty-five years. You may assume that over this time frame, new storages cannot be built."

Other staff centred inputs
Aspects such as the assessment details, handbook entry and a full schedule of the expected student and staff input on a week-by-week basis are provided as static HTML pages at the start of the subject. A web conference (described later) is used to provide news and instructions on a regular basis. These usually flow from instructions given in class, reminders of critical dates, or news of the availability of new material posted on the web site. It is largely a one-way communication.

Student Centred Inputs

Student home pages
Each student is required to publish material on the web site, and for this they require a home page. A template is provided which the students personalise. The template has pre-existing links so that as the students add files to the appropriate directories, they become live. Most of the material accessible from a student's page is password protected so that only the staff and the student owner can access it.

Group Home pages
Small groups of approximately four students maintain a home page, created from a template, which has links to assessable work performed by the group. In general, anyone on the Internet can access these documents. In particular, my intention is that other students in the class can see what their peers are publishing and can use that work in their own designs.

Library resources
The bibliographic details of all articles, books, standards and web sites that students refer to in their final designs must be published on the web site. Students complete an on-line form with the details and a form-to-email gateway sends the staff an email with the information. This was added to a web page on an approximately twice-weekly basis. Students receive an assessment reward for contributing resources to the library. Like all WebRAFT pages, this document is searchable by the search engine so students can search the library for particular items. Typically the class generates about 100 references. The maintenance of this page is

being automated at present, however another server must host the database functions because in general there is no provision for user supplied executable code on the WebRAFT server.

Creator/Authors	Web site area	Users
Staff	**Subject Home Page** • Brief • Schedule • Assessment Info. • Conference	Class, Individual Students
Individual Students	**Individual Home Page** • Diaries • Preliminary Report • Final Report	• Staff, individual reflection • Staff, conference feedback • Staff, next year's class.
Groups	**Group Home Page** • Literature Reviews • Brainstorming results • Draft Solutions	Other groups
Staff, groups and individuals	**Subject Library** • Data input form • Article references and summaries • Internet addresses.	Groups and individuals

Table 1. Main Areas of Environmental Engineering Design 1 Web Site.

Past reports

Many students learn best by example. My experience is that there is usually unequal access to past student's reports by currently enrolled students. To create a level playing field, some examples, both good and bad, of design reports from previous years have been posted on the site as PDF files.

Student to Student to Staff Communication

Asynchronous Conference

The asynchronous web conference facility is used to deal with student questions about various aspects of the subject. Several discussion forums have been set up to deal with issues such as web publishing problems and clarification of the brief. Students are encouraged to answer other student's questions if they feel they can. Students can also start a new discussion area if they wish.

Access to others submissions.

Most group publishing activities are placed in the public area of the group directory in order that members of other groups may see their work. This

is used in two ways. In a literature review task different groups investigate different aspects of literature related to the problem. The published group reviews can then be accessed by other groups to read a summary of the literature into an aspect of the problem they did not investigate personally. In other tasks, the same data is analysed and the group result published. Other groups can thus compare their outcome with another group's result.

Email

All students have their University provided email account automatically published on the web site and are thus readily available to send each other email via the web browser. Communication with staff by email on course related matters are actively discouraged. The conference is preferred for electronic communication by students to staff so that all class members can see the questions and answers.

The Role of Face To Face Communication

Lectures and discussion sessions

A small number of lectures are provided to present new material and to provide an opportunity for direct class discussion on important issues related to the project. Strategies for solving aspects of the problem are also developed in lectures to enable implementation at a later time by groups or individuals.

Practice Classes and Group Meetings

Practice classes are used in several ways. Computer laboratory classes are used early in the subject to ensure all students grasp the fundamentals of web publishing and web site maintenance. Small group discussions are facilitated in practice classes in the area of creative thinking and public participation processes. Short student oral presentations to the class on their literature reviews are a significant way of broadening the students' knowledge of all aspects of the problem and potential solutions. Outside of class, groups have varying numbers and lengths of meetings which are not pre-arranged by staff.

Field trip

A field trip to expose the students to a "real world" site that is related to the design is arranged. Usually about 2 to 3 hours at a site or sites under the guidance of an industry expert is provided in order to allow the students to relate their design problem to a similar problem or situation. The trip occurs about one third of the way through the semester. The main aim of the site visit is to help the students understand the scope of the

problem and to be exposed to some of the practical difficulties faced by professional engineers working on similar problems.

Student to staff communication

Reflective diaries - for self assessment and reflection.

Reflective diaries have been promoted as a means to help students gain a deeper understanding of the material they are studying. In 1999, students were asked to write about 100 words at five stages during the subject. Instructions on what to write were not specific, but suggestions were made that they could describe their feelings about the subject, their expectations, any problems they were experiencing with group work or their own performance. In 2000, more specific instructions were given to write about:

- What are your current expectations and how are they changing,
- How is your understanding of the problem changing,
- Whether the processes you are using to solve the problem are working, and
- Any other problems affecting performance.

Reports - for formative and summative assessment.

About half of the way through the subject, students were required to write a preliminary report. This report was intended to provide an opportunity for the student to write and receive comment on a document that would be a draft of introductory sections of their final report. It was also intended to get the students to think about the structure of their final report so that the vital last weeks of the semester could be more focused towards developing a "reportable" solution. The final report, which was a document of about 40 pages including diagrams, appendices, sample calculations, etc was the main item of assessment and was worth 60%. Submission of both reports to the web site was optional.

Results of Two Years Experience

Student web publishing

Despite these students being third year engineering students who were computer literate, none of the 70 odd students over the 1999 and 2000 cohort had ever attempted to do any web publishing. This was despite high levels of computer ownership (over 75%) and access to computers and server space in engineering computer laboratories to publish personal home pages. This was contrary to my expectations, which were that at

least one person in each group would have these skills and could share them with their colleagues. After about three weeks all students had mastered the fundamentals of creating a web page and using an FTP program to place it on the server. Many students saw this as a worthwhile challenge, but also criticised the low level of staff teaching support given in 1999, which was corrected in 2000. By the end of semester some students published their entire reports on the web site.

Conference participation

Participation in the web conference was left optional in 1999. One discussion topic was established called "Chats with experts". Students were instructed to record on this discussion the results of any personal contact that they made with professional engineers working in the field. My aim was to prevent the same person being contacted multiple times by different class members on the same topic. The count of the number messages written to the conference in 1999 was zero! In 2000, reading of conference messages was given a much higher profile. Much of my written communication to the students was via the conference rather that by email to the entire class, which was for me an easy alternative. Similarly, I made it clear to the students that I would not respond to non-personal questions related to the subject that were sent to me by email, except to ask them to ask the same question on the conference. Thus in 2000 most electronic communication went via the web conference. I am convinced that this is the preferable way from the staff perspective of the most efficient way to manage this type of communication. Although there was not a high level of questions answered by other students, this was in part due to rapid response (within 24 hours) by me to most issues raised.

In 1999 from a class of 37 I received 40 email messages during the semester directly related to the subject. In 2000 (class size 34), this dropped to 5 email messages, which were all of a nature not suited to asking via the web conference. Approximately 70 messages were posted on the web conference two thirds of the way through the semester. Of these 12 were initiated by staff and the remainder were in the main questions initiated by students and responses by staff. There were some instances of students answering questions and comments placed on the conference by students for information alone. In conclusion the volume of electronic communication has remained about the same, however the questions and answers are more easily accessible to the whole class.

Diaries

Students were asked to write five reflective diaries throughout the semester. The 1999 diaries have been analysed by classifying the responses into a number of key areas. The classifications were suggested by the diaries themselves. Table 2 shows the results of the classification process. Observations from the diaries were as follows. Despite the diaries having a small assessment value (1% each) student participation was quite high. Almost every student submitted diaries early in the semester and two thirds of students filling out diaries late in semester (when competing for time with a 60% submission in this subject and many other assignments). The number of issues raised per respondent varied between 1.8 and 2.9 with no particular trend evident. The responses were classified into positive and negative comments about the subject, teaching or learning. There were about twice as many positive comments as negative comments. The use of WebRAFT as a learning aid figured as one of the more prominent positive comments along with well functioning groups, direction of learning had been established, the subject was interesting, the preliminary report was a useful learning tool, as was the field excursion. These positive responses all outweighed the negative responses except that the project or problem to be solved was "daunting, overwhelming or confusing". Other prominent negative responses included web publishing problems (which were all overcome), a fear of lack of time to complete and students questioning the quality or quantity of their personal contribution. No students were critical of the use of WebRAFT in the manner used in this subject.

Quality of teaching surveys

Each year the University implements quality of teaching surveys of all subjects. The form of the 8 questions asked is not within control of the academic staff and are very general and open to interpretation by the students, however over time may give some insights into how a subject performs (or how the student population change). Students are requested to respond to up to 8 questions by giving a rating of 1(worst) to 5 (best). Recent results for the subject are given in Table 3. Over the four years the staff teaching the subject and the subject structure has been fairly constant, with the exception of introduction of WebRAFT as a learning tool in 1999. The ratings do not show any significant trends over time.

The volume of work has increased slightly with the introduction of the need to learn how to publish on the web and the request to submit

reflective diaries, however this has not caused undue concern among the students on that question. It may be that other aspects of the work have been eased due to the use of WebRAFT for student communication.

Classification	Diary 1	Diary 2	Diary 3	Diary 4	Diary 5	Sum of Responses	Positive Responses	Negative Responses
Total response (33 students enrolled)	31	32	31	25	21	140		
Group is working ok	21	14	9	5	12	61	61	
Direction found			19	13		32	32	
WebRAFT good	12	4	6	3	3	28	28	
Interesting	13	14				27	27	
Prelim report good				22		22	22	
Field trip good		20				20	20	
Success!					17	17	17	
Good result anticipated				11		11	11	
Learnt a lot					10	10	10	
Publishing problems solved		5				5	5	
Exciting	3					3	3	
Daunting, confusing or overwhelming	12	3	8			23		23
Web publishing problems	14	1				15		15
Lack of time fear				7	7	14		14
Personal contribution insufficient		5	7			12		12
Trouble finding info	10		1			11		11
Health Problems	3	2	1	1		7		7
Unclear of direction		4			2	6		6
Critical of some aspect		6				6		6
Mid semester blues			5	1		6		6
Field trip pointless		5				5		5
Modelling problems				5		5		5
Group problems	1	2		1		4		4
More web publishing instructions required		1				1		1
Sum of issues raised per diary	89	86	56	69	51	351	236	115
Average issues/respondent raised	2.9	2.7	1.8	2.8	2.4	2.5	1.7	0.8

Table 2. Classification of responses in student reflective diaries.

Student Achievement

Frequency distributions of grades achieved by the students in the subject over the last four years are shown in Table 4. The proportion of high achieving students was lower in 1999. The reasons for this are unclear at present. Three students failed in 1999, however, this can be traced to total

lack of work by the individuals rather than some other cause related to teaching or presentation style.

Staff Input

Detailed records of staff time resources have not been maintained. As with any new approach there has been an investment in learning new skills and analysing and understanding new learning interactions. The more important aspects are the ongoing operational time costs. Face-to-face contact has increased by about 5 person hours through the need to introduce web-publishing skills and then provide computer laboratory support. This is expected (hopefully) to be a transient cost since these skills are now being acquired in secondary school education. The assessment load has increased by about 25 minutes per student due to the addition of the reflective diary component. This may be reduced in future by assessing only a sample of diaries (say any 2 of 5), in order to keep the incentive for students to write the diaries and to have the diary material available to review for research purposes, but reduce the assessment time. The main items of assessment are the preliminary and final reports, for which the load has not changed.

Question	1996	1997	1998 *	1999 [a]
I had a clear idea of what was expected of me.	3.6	4.1	3.2	3.2
This subject was well taught.	3.2	3.7	2.6	3.3
This subject was intellectually stimulating.	3.8	4.0	4.0	3.8
I received helpful feedback.	na	3.7	3.2	3.3
Staff showed an interest in the academic needs of the students.	3.5	3.8	3.8	3.9
The volume of work was appropriate.	na	3.9	3.8	3.6
The multimedia based technology helped me learn effectively	na	na	-	4.0
I regularly made use of material made available by staff on the internet.	na	na	-	4.5
This subject helped develop my learning skills	3.5	na	na	na
Average	3.5	3.8	3.4	3.7
* less than 1/4 of class responded to survey; [a] WebRAFT used in 1999., na question not asked in that year. - no respondent to that question				

Table 3. Quality of Teaching Survey Results.

Grade	1997 (%)	1998 (%)	1999 (%)	2000(%)
< 50	4	0	9	3
50 - 64	15	11	15	25
65 - 74	26	37	45	31
> 75	56	53	30	41
Number	**27**	**38**	**33**	**41**

Table 4. Percentage frequency distribution of student grades over the last four years.

Web site maintenance is an ongoing requirement, however, the extent to which this requires additional resources is debatable. At present it arguably does take extra time, however this is partly a result of adjusting working habits to a web based delivery culture. For example, if documents are prepared for paper delivery and then converted to HTML there is obviously an overhead, however as skills and work practice change to make document preparation for web delivery become the norm then the additional work will be minimal if any. Reductions in time spent photocopying and printing, putting messages on noticeboards, organising class lists and groups, and delivering content that might be more easily assimilated by the students from the web are all real. The insistence on students using the web conference for electronic communication has reduced the email response time requirement but increased the time spent on the web conference. However, this time input is likely to have been much more cost effective in responding to queries because of the accessibility of questions and answers to the whole class. In summary, there has been an increase in time spent on the subject, however, when judged against my perceived improvement in teaching and learning satisfaction of both the students and myself the time expenditure has been justified. Having the choice to use either the paper-based or WebRAFT form of delivery, I have no hesitation in favouring the latter as the preferred method.

Conclusions

The use of problem based learning and the WebRAFT platform has been successful from both the staff and student point of view. WebRAFT has fulfilled the main specifications of an improved method of document management and an improved method of class communication. The use of reflective diaries has provided a useful insight into student learning and can alert staff to problems that need to be rectified at an early stage. The main lesson to be drawn from the reflective diaries for project based learning is that many students find the size of the project daunting, especially if this is the first time they have attempted a large project themselves. Given this fact, providing a structured framework to attack the problem and providing opportunities for interim submissions for assessment and feedback are very important.

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