Learning Approaches in University Calculus: The Effects of an Innovative Assessment Program

Marina Penglase
University of Western Sydney
<m.penglase@uws.edu.au>

This paper reports findings on students' approaches to learning from a larger study which investigated the effects of a university calculus assessment program on students' attitudes, perceptions, learning approaches and associated learning quality. Data on sixteen students' learning approaches were collected through the use of questionnaires, interviews, assessment submissions and anecdotal evidence. The data suggest students' use of deep learning approaches was facilitated by the nature of assessment tasks and students' perceptions of assessment requirements, and had a positive effect on learning quality.

> The quickest way to change student learning is to change the assessment system. (Elton & Laurillard, 1979, p.100)

At the higher education level, as with school education, research has clearly identified assessment as one of the most critical factors in the issue of student learning quality, repeatedly demonstrating that assessment methods tend to drive learning (Biggs, 1996). More particularly, it appears to be students' perceptions of assessment requirements which cause them to choose specific learning strategies and to decide on which types of understanding they will aim for in their study of course content (Biggs, 1992). A critical issue then, in maximising the value of assessment procedures as a learning tool, is that they need to be appropriate; chosen with an understanding of the types of learning they promote, for the purpose of meeting specific learning outcomes (Brown & Knight, 1994).

This paper reports findings from a study which investigates the effects of an assessment program on learning quality in the study of university calculus. The design of assessment tasks was based upon the idea that the quality of students' learning is related to the approaches they use in their learning and that achievement of the desired types of knowledge and understanding is closely linked to the appropriate choice and use of assessment strategies. The focus of this paper is to report on students' use of deep approaches to learning in their completion of this assessment program.

Literature Review

The tendency, traditionally, by higher education teachers to separate teaching from assessment and to view assessment as a means for grading only, has changed very little even with the current emphasis upon the evaluation of educational procedures (Courts & McInerney, 1993). It is very disturbing, therefore, that research results continually confirm that higher education students will study what they think will be assessed, at the cost of understanding the material if it seems necessary. For example: Entwistle and Entwistle (1992) found that students consciously chose specific study goals based upon their perceptions of the forms of understanding needed to meet assessment requirements; and Laurillard (1984), who reached similar conclusions regarding science students' completion of particular problem-solving tasks, added that if it was perceived that there was no benefit to be gained from preserving the contextual content of the problem, the method used to solve it tended to result in distortion of the structure and the manipulation of isolated elements.

One of the frameworks used to examine the nature and quality of students' learning within higher education is founded upon the idea that the key to discovering ways and means of improving student learning is through the study of students' approaches to learning. This framework has its origin in the work of Marton and Saljo (1976a & 1976b) who identified two categories into which students' perceptions and organisation of the subject matter of learning tasks fall. These have become known as *deep* and *surface* approaches to learning. The term "deep" approaches describes learning approaches that result from the intention to understand a given task. It entails focusing upon "what is signified"; organising and structuring knowledge and content into a coherent whole; relating previous knowledge to new knowledge; linking knowledge from different courses and theoretical ideas to everyday experience; and relating and distinguishing evidence and argument (Ramsden, 1992, p. 46).

In contrast, a surface approach to a task involves simply completing the stated requirements of a task. Predominant aspects of this approach are memorising, arranging and using disconnected parts of course content without relating these to the structure or meaning of the task as a whole, failing to distinguish principles from examples, and viewing a task as an external imposition. More recently, a third approach has also been identified which, like surface approaches, has an extrinsic motive. This has been labelled the *strategic orientation* or *achieving* approach. Using this approach, time is allocated to tasks according to their potential to earn grades (Biggs 1987).

There is a substantial body of research which links surface approaches with low course results and, to a somewhat lesser extent, deep approaches with high grades. For example, an investigation by Entwistle and Ramsden (1983) revealed that students who consistently used deep approaches were more likely to obtain first or upper second class honours degrees. Other studies involving British, American and Australian students have resulted in comparable findings (Biggs, 1987; Ramsden, 1992).

A number of general principles appear to facilitate an assessment activity's usefulness as a learning tool. It needs to be perceived by students to be relevant, closely linked with real-world problems and situations (Black, 1993). It must reflect course aims and objectives and, hence, the skills and concepts to be learned, and should be as explicit as possible and given in such a way as to enhance student motivation (Crooks, 1988).

Each of these principles was employed in the design of the assessment program which is the focus of the study reported in this paper. Opportunities for self-assessment were also included in the program as there is much evidence to suggest that the use of strategies that encourage or require self-assessment can have a substantial impact upon both the nature and quality of student learning (Kenney & Silver, 1993).

Description of the Research Situation

The Course and Assessment Program

The assessment program that is the focus of the study, was the assessment component of a second year, two-semester calculus course within a Bachelor of Education degree program. The motivation in the design of this assessment program was to encourage students to think deeply about calculus, to engage in self-assessment and reflection, to strive for mastery in the understanding of course content, and to gain an appreciation that mathematics is much more than applying rules to obtain a solution but, instead, is a human endeavour that enables us to make better sense of the world.

Table 1
Task Descriptions, Weightings, and Learning Goals for each Assessment Activity

Type of Task	No. of tasks, weightings	Description	Learning Goals
Mastery Tests:	4, 11% each	Involved the submission of the best of three similar papers, completed in three sittings, generally over a period of three weeks.	1. That students may master the "basics" of the course content. (The "basics" were covered within the sections of "pass level" tutorial questions in the Subject Guide.) 2. To encourage students to reflect upon and assess their own work and to learn from their mistakes.
Assignment 1	10%	Entailed the use of calculus in modelling real-world phenomena.	In order that students may gain an understanding: 1. of how calculus can be applied, and 2. that real-world applications are not neat like textbook exercises.
Assignment 2 (optional)	14%	An investigative exercise involving different ways of defining calculus concepts for the challenging of ideas and thought processes.	In order that students may: 1. gain an appreciation that there are alternative ways of looking at mathematical problems and ideas, and 2. have their ideas and thought processes challenged about the nature of mathematics and familiar mathematical problems.
Concept Essays:	6, 2% each	Six short essays explaining their understanding of fundamental calculus concepts, the historical development of calculus and the application of calculus concepts.	That the course content may play a part in: 1. giving students an understanding that mathematics is a human endeavour that enables us to make better sense of the world around us, and 2. dispelling the attitude that mathematics is just a collection of rules that is used to get the right answer.
Optional End-of-year Exam:	1, 20%	Comprised calculus questions that tested an advanced level of understanding of course content.	1. To give those who strive for excellence something to strive for. 2. To encourage all students not in the above category to concentrate on the "basics". 3. To achieve a spread of grades.

The program consisted of four sets of mastery tests, six concept essays, one compulsory and one optional assignment, and an optional end-of-year examination. A workfolio containing all completed assessment tasks and a number of class activities was

to be submitted for marking at the end of each semester. Table 1 provides a description and the weightings of tasks, and outlines the lecturer's purpose for each activity.

The Sample Group

The participants were 16 trainee teachers in their second year of a Bachelor of Education (Mathematics). The group consisted of seven males and nine females ranging from 19 to 37 years of age. Four of these were 19 year-olds, eight were aged between 20 and 25, two were between 26 and 30, and two were in their 30's.

Method

Qualitative techniques were employed to gather data on the learning strategies and associated attitudes, perceptions and ideas of each student as these related to their completion of the various assessment tasks and their learning of course content. The sources of data were: class sets of questionnaires administered upon the completion of mastery tests, concept essays and Assignment 1; three in depth interviews with two student volunteers; student assessment submissions - particularly Concept Essay 6 submissions; and to a limited extent, anecdotal evidence. (Students' submissions of Concept Essay 6 required a written discussion of the effects of the course on students' view of calculus. Full marks were assured upon submission, no matter what the content, to give students the freedom to write what they wished without fear of being penalised.)

Ramsden's (1992) summary of the learning strategies entailed in students' adoption of deep approaches was used to examine the nature of students' use of deep approaches in their completion of assessment tasks and associated learning of course content. These deep-approach learning strategies are listed in the following section as headings under which the findings of this study are reported.

Results

Following is a summary of the results of an analysis of sixteen students' comments about their learning in relation to their use of deep learning approaches in the completion of assessment tasks and their learning of course content.

Focus on "what is signified" (e.g., the concepts applicable to solving the problem) and organising and structuring content into a coherent whole. The comments of 13 students fitted this description. These students explained that the need to write about concepts and to define mathematical concepts in their own words in concept essays and (to a lesser extent) in lectures had required that they

- gain a clear understanding of concepts.
- "think deeply" about the concepts.
- replace memorisation for understanding.
- engage in "a lot more thought about topics".
- discover the need for generalisation and use this in forming concept definitions.
- engage in personal research.

In having to explain and justify assignment solutions, one student also remarked that he needed to gain a clear understanding of the concepts he was working with. Another felt that the course emphasis on conceptual understanding had so much changed her approach to study in mathematics that she was now "more interested in concept than content", tending, as a result, to spend more time on gaining conceptual understanding than in drill and practice.

Relating previous knowledge to new knowledge and relating knowledge from different courses. Four students reported that they had used this learning strategy in their studies, three of these in the completion of various concept essays. The end-of-year comments of two of these latter three provide clear illustrations of this strategy in practice:

> More importantly ... [concept essays] made me look over my notes and try to think of extensions of them, other applications they can be related to and also how the ideas in our notes relate to other work we have done. (S1)

> But what is important is mathematics topics are related in one way or another. I started to think about this when I discovered calculus is related by the F.T.C. [Fundamental Theorem of Calculus]. After that I tried to think about how the different subjects I did were related. (S4)

One of the four students simply devoted most of his submission to outlining the ways in which his understanding of relationships had increased as a result of the course, without explaining how this had been achieved.

Relating theoretical ideas to everyday experiences. The data indicated that four students had used this strategy. One student's concept essays all contained examples of her attempts to do this. Another found it necessary to relate his theoretical understanding to real-world applications in order to explain and justify his assignment solutions:

> This opportunity to explain and justify my solutions deepened my theoretical understanding as it helped me see the real-world applications of the theories I had learned. (S16)

This student added that in Assignment 1 he had needed to "experiment with different equations I thought might be suitable" and to research "similar problems" in an attempt to improve his "initial model". Two others reported similarly with regard to Concept Essays 1, 3 and 4.

Relate and distinguish evidence and argument. The data gave evidence that most students strived to do this in the completion of various assessment tasks. For example, fourteen students' Concept Essay 1, 2 and 3 comments indicated that they were engaged in distinguishing and relating evidence in the reading and research required. The following end-of-year comments from two of these students illustrate the use of this strategy:

> With all the concept essays ... I had to be absolutely clear in my own mind about the concepts before I would put anything in writing ... . (S2)

> ... There were times where the link between the problems I had to solve and the theoretical knowledge I had gained were only strong once I had read further into the relevant subjects from my fathers collection of calculus books at home. (S16)

Internal emphasis demonstrated. Evidence of internal emphases in students' learning could be described in the following ways.

References to learning as personal gain. Fourteen students reported aspects of personal gain from their calculus studies, mentioning one or more of the following: the nature and quality of their newly-acquired understanding, the extension of their understanding of concepts and the subject as a whole, and the benefits of various course focuses and various aspects of their learning to their own quality of teaching as future mathematics teachers.

Students' references to personal gain were closely associated with reports of appreciation for particular course focuses, increases in interest and enthusiasm, and changes in ideas, and are summarised, below, under those headings.

Increases in appreciation of deepening understanding as a result of course focuses. This was evidenced in Concept Essay 6 submissions by fourteen of the fifteen students who had submitted this task. Each of these included some mention of an appreciation for

aspects of the course that were believed to have caused students to put more thought into the subject than they felt they had done in previous mathematics courses. One student, for example, observed:

> From completing this years course I realised that I had managed to complete other courses and high school without really thinking about or understanding the concepts or principles behind the problems I was solving. (S9)

Concept essays, assignments and lecture presentation were thought to have been the most effective means of deepening understanding. The aspects that students valued the most from these components of the course were: an emphasis on conceptual understanding (8 students); a focus on understanding the relationships between concepts (4 students); an emphasis on understanding as opposed to the memorisation of procedures (3 students); verbalising understanding or expressing their knowledge in words (5 students); learning about the historical development of calculus (6 students); and real-world application (3 students).

Substantial increases in interest in, and enthusiasm for, the subject as a whole. Eight students reported these types of changes. The following comment was indicative of the types of remarks these students made on this issue.

> I find calculus interesting now, as I can see where it came from, the problems mathematicians had with explaining calculus (i.e. limits) and the theorem that makes calculus a "big happy family" (ie FTC). (S4)

One of these simply stated that her newly-acquired interest in, and motivation for, learning about calculus was the most significant aspect of her learning in the subject. Three others had engaged in extra personal reading and research as a result. Another reported that her interest in the subject had grown to such an extent that while working on the second assignment she "became wrapped in the idea of another definition of differentiation", adding that the realisation that

> all of the research and study had been done previously didn't deter me and the results of my investigations were very exciting. (S13)

Changes in ideas on calculus and the nature of learning. Fourteen students reported changes in ideas on calculus. One simply stated that "by doing this course my view of learning and understanding [has] completely changed". Nine reported that they now understood the study of calculus and its uses to be much more expansive than they had previously thought. Five of these observed that calculus had become for them much more than a set of procedures, while one student commented that, throughout this calculus course, he had come to realise that his "idea of what calculus is will be continually changing" as he continues learning about it because he now appreciated that "we have only scratched the surface".

An overview of the data regarding students' adoption of deep approaches in their study is provided in Table 2.

Table 2
A Summary of Data Regarding Students' use of Deep Approaches

Description of Study Strategy	Student															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
- Focusing on "what is signified".	*	*	*	*	*	*	*		*	*		*	*		*	*
- Relating previous knowledge to new knowledge and relating knowledge from different courses.	*				*										*	*
- Relating theoretical ideas to everyday experience.	*									*	*				*	*
- Relating and distinguishing evidence and argument.	*	*	*	*	*	*	*	*	*	*		*	*			*
- Internal emphasis demonstrated.	*	*	*	*	*	*	*	*	*	*		*	*		*	*

Conclusions and Discussion

The data indicate, then, that fourteen of the sixteen students, and possibly a fifteenth student to a lesser extent, adopted approaches which can be described as "deep" in their completion of assignments and concept essays. They also suggest that this type of approach was not the sort in which at least twelve of these had engaged in their mathematical studies prior to this course.

The admissions by several students that the nature of assessment tasks had "made" or "forced" them to engage in approaches which were identified as "deep, appear to agree with the findings of the higher education studies citied in the Literature Review which conclude that students' concentration on gaining understanding in the completion of assessment tasks is in direct response to students' perceptions of the lecturer's expectations. Not surprisingly, this is closely linked to a focus on obtaining desired marks or grades, as opposed to improving their quality of learning. This was illustrated in the present study by remarks such as "... but that's [understanding the subject] irrelevant of course because all we have to do is pass it [the course]" and, "... because they [concept essays] were worth so little ... the amount of work needed to get a good mark was not really worth it" (referring to their usefulness in terms of learning). Nonetheless, there was much evidence to suggest that the majority of students actually came to value the types of learning that the lecturer had been trying to encourage. This is well illustrated by the candid comment of a case-study student regarding Assignment 1:

> It was just weird. Like just sitting there talking about Maths and getting really interested in it, and [personally] thinking "What's happening to me?!" (S7)

Finally, the findings reported here lend support to research which suggests that students' adoption of deep approaches is associated with problem-based curricula, the relevance of subject matter, and focusing upon meaning, or as Biggs (1989) describes it, "involvement in content". In particular, they indicate that students' adoption of deep approaches was encouraged most by a concentration in lectures and assessment tasks upon

the development of conceptual understanding, an emphasis on problem-solving and real-life application and by the historical development of the subject. The lecturer's enthusiasm for, and personal involvement in, the subject were also found to be influential in students' adoption of deep approaches.

Implications

In view of these results, higher education teachers should ask themselves whether the assessment tasks they choose do indeed focus upon the type(s) of learning they desire and do encourage study approaches which enhance students' learning. It is clear that there is also a need to ensure the presence of clear learning outcomes and consistency of focus throughout all components of a course - course content, teaching style and strategies, the nature of assessment questions and the types of assessment tasks – in order that the effect on the nature and quality of students' learning, as they strive to meet a teachers' expectations in the completion of assessment tasks may perhaps be strengthened.

It is well documented that only a very few students in any university course gain a solid conceptual understanding of the subject under study, that most tend to know only learned rules and techniques, and that few are able to see relationships between concepts and topics or apply their learning to real-life situations (Harel & Trgalová, 1996). The results of this study give some idea of the ways in which the occurrence of these problems may be markedly diminished and therefore have the potential to be of substantial value to higher education teachers, and also to high school teachers who face similar problems.

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