
On the use of audio-tapes for teaching vector analysis to engineering undergraduates

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Abstract An audio-tape with an accompanying booklet of notes has been prepared specifically for teaching the topic of vector analysis to engineering undergraduates in their second year of study at Sheffield University. The audio-tape package was designed to replace four conventional lectures. The implications of introducing an innovative teaching practice into a mathematically based discipline are discussed. The reactions of two cohorts of students on whom this teaching innovation was trialled are described. It was deduced that students are likely to be more receptive to an alternative teaching practice if they are encouraged to participate in the decision-making processes concerning the details of its implementation. Such activities generate the concept of 'shared ownership', which tends to promote more positive student feedback.

Keywords audio-tapes; mathematics for engineers; vector calculus

Introduction

This paper is concerned with the evaluation of the use of an audio-tape with an accompanying booklet as an innovative approach to teaching part of an engineering mathematics course to second-year students at Sheffield University. Here the term 'innovation' is used to denote any change that is new to the context in which it is introduced [1]. The aims of the project were to promote learner autonomy by:

- encouraging students to take more responsibility for planning their work agenda;
- promoting students' awareness of alternative teaching methods to the traditional lecture;
- enabling students to work through material at their own pace – this was considered to be important due to their wide-ranging mathematical abilities.

Mathematics has traditionally been regarded as one of the most difficult subjects at 'A' level [2]. The need for mathematics as a service subject for engineering disciplines in higher education has long been recognised, yet, for many years, universities have expressed disappointment that such courses tend to be undermined by the inability of the undergraduates to transfer their mathematical skills to those of their particular discipline [3]. One of the main aims of a mathematics course for engineering students is to enable them to develop a competency in a broad range of mathematical skills and to gain an insight into how to apply these principles to a range of engineering systems. However, due to limitations on the time allocated for them, engineering mathematics courses tend to focus on general mathematical techniques. A few examples related to engineering processes may be presented, but

usually applications are discussed in the engineering courses. Factors which have had profound, though presumably unintended, effects on engineering courses include the poor recruitment of mathematics and science graduates into school teaching and the perceptions and attitudes of students entering university [4]. Foster illuminates problems that he encountered in teaching those aspects of chemical engineering subjects that are composed of hierarchies of concepts [4]. Engineering mathematics falls into this category.

Parsons [5] found that students develop their understanding of mathematics through a combination of coming to grips with fundamental concepts and working through examples. Some students are prepared to accept on trust information that they do not immediately understand so that they can make progress through the related exercises, confident that as they do so their understanding will develop. Others struggle to gain a strong grasp of the underpinning fundamental principles before they feel confident to attempt problem-solving exercises. The terms 'shallow learning' and 'deep learning' are often used to describe two distinct ways in which students might approach the task of acquiring knowledge [6]:

- 'Shallow learning' is said to have taken place when a student has learnt a list of disjointed facts without properly understanding how they relate to each other or to the global picture.
- 'Deep learning' occurs when students delve below the surface of a text in order to interpret its meaning and to understand the 'big picture'.

Thus, students of the former disposition tend to use a surface approach to learning as a precursor to deep learning, which they hope will occur by practice. Although one might expect students in the latter category to make better progress, those who seek to establish learning from fundamental principles may eventually feel too embarrassed to keep asking questions of the teaching staff until they have completely understood the necessary concepts.

We postulate that for the purpose of an undergraduate engineering mathematics course, where students have to take a terminal examination, an outlook involving a mixture of the deep and shallow approaches to learning is perhaps the best policy, as the student's main short-term goal is to do well at the examination. In order to do well at the examination, students should understand as well as possible the fundamental principles underpinning the course but, in view of the limited time, they should focus their efforts on developing a strategy on how best to tackle the set problems. Thus, time management is a key issue in student learning.

The enhancement of learner autonomy has become a major concern in higher education [7]. Learner autonomy aims to promote the self-development of an individual by means of appropriate strategies, techniques and materials. Holec [8] defines learner autonomy as 'the ability to take charge of one's own learning'. We believe that the purpose of a university education is to guide undergraduates towards the goal of becoming autonomous learners. Students are likely to benefit from a structured programme which moves gradually from a transmissive form of teaching to one where they are given the opportunity to take increasing responsibility and initiative for their own work planning. Continued motivation of students is vital, and

staff need to be conscious that some students may not be aware that they do not understand a concept and may therefore not realise that they ought to be seeking help from support staff. Learner autonomy can be promoted if students assume an increasing level of responsibility for the planning of their work schedule; that is, their time management skills should be promoted.

This paper is concerned with the evaluation of audio-tapes (with accompanying notes) for teaching the topic of vector calculus to second-year engineering students at Sheffield University taking the engineering mathematics course ama248. Traditionally this course has taken the form of two lectures and one problem-solving class each week for the duration of a 12-week semester. It is assessed by a 2-hour written examination. Week 7 is regarded as a 'reading week', during which no classes are scheduled. We wanted to introduce a change to the normal teaching format in order to promote learner autonomy. The audio-tape package was designed to replace four conventional lectures. The project was run over two successive academic years. The effectiveness of this teaching innovation as a tool for promoting learner autonomy is discussed. Due to the wide range in mathematical ability of students taking this course, it was thought that such an approach would be welcomed by the students, as it would allow them to work through the material at their own pace. Furthermore, an initial enquiry revealed that the vast majority of students on this course had easy access to a cassette tape player.

Design of the teaching innovation

In this section the perceived benefits of using an audio-tape-based teaching medium are considered. This is followed by a discussion of the skills we hoped the students would gain from the project.

Perceived benefits of audio-tapes

In the present educational climate, both staff and students are becoming aware of the complex ways in which learning is effected. The uniformity of 'transmission teaching' is being viewed in an increasingly unfavourable light [9]. Motivation is a key factor affecting a student's ability to concentrate. Common motives for students include the desire for relevance, curiosity, the enthusiasm of the lecturer and, not least, the assessment of knowledge gained.

Variations in stimulation in the learning environment can maintain or even enhance a student's attention. Lectures and audio-tapes may not be typically regarded as ideal teaching methods for maintaining student attention unless a special effort is made to prevent their minds from wondering. MacManaway [10] reported that 84% of his students said that 20–30 minutes was the maximum length of time for which they could give full attention in a lecture. Yet the standard duration of a lecture is 50 minutes.

A portable audio-tape package has the advantage over a standard lecture that students can choose the duration of each session that they spend listening to the tape. It allows them the freedom to move to a different activity once their attention starts

to wonder. Although the total recording time of the audio-tape produced for this project is one hour, after intervals of roughly 10 minutes students are advised to stop the tape and attempt some problems. Problems were carefully selected in order to be appropriate to the students' level of attainment and to promote motivation. Furthermore, students may choose to rewind the tape and listen again to a particular section to reinforce the ideas that were introduced. It is not possible to 'rewind' a lecture in a similar way.

The audio-tape package aims to enhance a student's ability to concentrate by providing auditory stimulation, visual stimulation and novel stimulation. The 'novel stimulation' arises from the fact that the audio-tape package is presented to the students as an 'innovation', that is, it provides a 'change' from the usual forms of learning media that they are familiar with. Audio-tapes are cheap to produce, although they are considerably more time consuming to prepare than an equivalent set of lectures. They are suitable for revision purposes and students may listen to them at any convenient time. We endeavoured to ensure that the audio-tape package had clear aims, was well structured and highlighted key results.

Educational goals

Houston [11] edited a collection of papers describing 18 case studies that illustrate some of the innovative teaching practices taking place in mathematics departments in establishments of higher education. The purpose of the volume was to arouse curiosity in its readers (typically university mathematics lecturers) in the hope that they might build on the experiences described by adapting them for their own teaching purposes. The teaching and learning strategies covered a broad range of methods, including project work, independent study, group work, peer assessment, self-assessment and computer-assisted learning. The development of transferable skills is being increasingly regarded as an important 'by-product' of most undergraduate courses. Exposure to a range of teaching methods is likely to provide students with more opportunities to enhance their transferable skills, and hence their employability. Houston [11] identified the following transferable skills and competencies as being potential by-products of mathematically based courses: initiative, independence, teamwork, data analysis, management/leadership, time management, planning and organising, decision making, written communication, oral communication, information finding, information technology and problem solving. We believe that the development of students' abilities to read mathematical texts and the enhancement of their listening skills are important competencies that should be added to this list.

The course syllabus for the second-year engineering mathematics course for engineers (ama248) is tightly constrained by the home department in order to ensure that students have the opportunity to gain the mathematical competencies needed to enable them to make progress with their mainstream engineering courses, which are closely monitored by the relevant professional bodies. A by-product of this is that the students should exhibit an inherent motivation to master this course. A list of

key points was drawn up and the subject matter was organised within a hierarchical structure.

Particular care was made when explaining issues which, based on our previous teaching experiences, we felt students frequently found difficult to understand, for example the differences between scalar and vector operators. We sought to include examples that arose in engineering processes, such as those related to fluid flow. At appropriate intervals exercises were posed in order to encourage the students to take stock of what they had just learnt, reflect on any new ideas introduced, or to enforce a change of activity (e.g. from listening/reading to thinking/writing). Repetition and revision of the ideas introduced in the package were encouraged by the provision of a supplementary sheet of exercises. Repetition is not necessarily boring for students who have already grasped a new concept; rather, it serves as an important aid to remembering.

A comprehensive set of typed notes was prepared to distribute along with the audio-tape. Their purpose was to replace the notes that the students would have copied down in the four lectures usually allocated to the topic of vector analysis. The notes were carefully produced in conjunction with the scripted audio-tapes so that the two learning media could be used in a complementary manner, with the aim of maximising their effectiveness as a learning resource. The main educational aims of the notes were to give information, save the students from having to make their own notes (thus relieving pressure on their time) and to provide training in reading mathematical literature.

Implementation of the teaching innovation and student feedback

Project 1

The first cohort of students to experience the audio-tape package on vector analysis were those taking course ama248 in the academic year 1999/2000. We shall henceforth refer to this as 'Project 1'. In order to accept innovations in teaching, students need to be psychologically prepared. It is important to try to establish the goodwill of the students beforehand, in the hope that they will be willing to accept the challenges presented by an innovation with an open mind. In an attempt to achieve this, at the start of the course we described the project to the students and explained what we believed to be its benefits, namely:

- The package would enable a change to the routine teaching/learning mode offered by traditional lectures.
- It would be portable.
- It would allow them flexibility as to when they worked through the material while also forcing them to take more responsibility for their own learning.

Feedback on the project was sought via interviews and questionnaires. The main difference in these two techniques is the degree of anonymity, and hence associated freedom of expression, that they offer the students. The interviews were conducted by two members of staff from Sheffield University's Learning Media Unit who were

interested in the project but who were unknown to the students. We felt that the students would talk more openly to them than to the lecturer.

Course ama248 is divided broadly into five subject areas, each taking about four lectures to complete: Fourier analysis; vector analysis; D'Alembert's wave equation; partial differential equations; and optimisation. Thus the second topic on the agenda, vector analysis, is usually covered during weeks 3 and 4. We decided to keep to this agenda and informed the students that the audio-tape package would replace the lectures in those weeks, though the examples classes (see above) would still take place. We had thought that the continuation of the weekly examples classes in the two weeks devoted to the audio-tape project would have provided excellent opportunities for the students to seek clarification on any concepts introduced in the audio-tape package that they did not fully comprehend. We were therefore disappointed that the first examples class was poorly attended and that only two students attended the second class. As it turned out, these were two conscientious students who had already mastered all of the material and did not wish to raise any queries. Were we to assume that the rest of their classmates had also completed the work to their satisfaction but had just chosen not to attend the problems class? On the contrary, we later found out that a significant number of students had not attended because they had chosen not to work through the package during the designated weeks. A few had such severe difficulties in mastering the material that they did not know what to ask. Bligh [12] postulated that 'most students who do not understand an explanation cannot say why, and many, not wishing to reveal their ignorance, would not do so if they could'. Some students had not attended the examples classes due to the cancellation of the preceding lecture at 9 a.m. They did not feel it was worth getting up in time for an examples class at the ungodly hour 10 a.m.! Other responses suggested that students preferred to ask questions during the lecture as and when a concern arose. They did not like having to jot down their queries in order to seek clarification in the weekly examples class.

Another reason for holding examples classes during the audio-tape project is that they provide a useful forum for obtaining informal feedback. Thus, from the first examples class, we were able to gauge how the audio-tapes had been received, and whether they were proving to be effective. Although attendance at the first examples class was much lower than expected, those students who attended did seem to be making good progress on the material set and appeared to be working happily and conscientiously. However, later feedback from interviews with the students, and from questionnaire results, presented a somewhat different picture. With hindsight, it seemed apparent that those who had attended the examples class were a 'self-selecting group'.

Analysis of questionnaire responses for Project 1

In order to obtain feedback on Project 1 we compiled a single-page questionnaire with the following questions:

- (1) Have you worked through the material yet? (a) Thoroughly, (b) Partially, (c) Not at all.

- (2) Approximately how many hours in total have you spent working on vector analysis?
- (3) If you have not spent much time on the material, please would you state why this has been the case?
- (4) Did you attend either of the two examples classes?
- (5) If you did not attend either of the two examples classes please could you give the reason why?
- (6) Do you think this audio-tape package adequately replaces four conventional lectures on vector analysis?
- (7) Which teaching method do you prefer? Why?
- (8) Can you suggest any ways in which the audio-tape package might be improved?
- (9) Do you have any other comments on the package?

Students were given 10 minutes of class time in week 5 to complete the questionnaires. From a class of 56 students, 30 completed questionnaires were received. Just two students claimed to have worked thoroughly through the material, while 21 students had partially completed the work, and, rather worryingly, 7 students had not yet looked at the package at all. Students had been advised that for every timetabled contact hour they were expected to undertake a further hour of independent study. In weeks 3 and 4 there had been a total of six hours allocated for mathematics (two lectures and one examples class each week). Thus, by cancelling the four lectures, over the two-week period of Project 1 we had expected them to spend 10 hours working independently through the audio-tape package and accompanying problem sheet in addition to attending the two scheduled examples classes. This would have brought the total amount of time spent working on vector analysis to 12 hours. Thus it was disappointing to discover that none of the students had spent more than six hours on the project. In fact, over two-thirds of the students had spent less than four hours doing this work. The most common reasons given for this lack of effort were:

- lack of motivation;
- projects for other courses were given priority;
- they found the material to be boring, or difficult;
- they simply chose to leave the work until reading week.

Only 8 out of the 30 students who completed the questionnaires had attended at least one of the examples classes. Without the preceding lecture, several students lacked the impetus to turn up for the examples class. Others had chosen not to come because they had not yet looked at the material.

When asked whether or not they thought the audio-tape package was an adequate replacement for four conventional lectures on vector analysis, a resounding 70% said 'No', with a further 10% being undecided. Just six of the students considered the package to be an appropriate alternative. Only five students preferred the audio-tape package to lectures. Encouragingly, the reasons which led them to this conclusion were ones which we had thought to be relevant when designing the project: they

could work at their own pace and to their own timetable, and they could replay the tape if they had not immediately understood the material. So, at least in the eyes of some students, our conjectures had been right and our efforts had been appreciated.

Interviewing the students

Student's assessments of the audio-tape package were sought as an aid to making appropriate improvements to the course in subsequent years. As many of the students involved in Project 1 had indicated that they were intending to work through the audio-tape package during reading week, we thought it would be informative to seek further student feedback shortly afterwards. Consequently, in week 9 (i.e. two weeks after reading week) informal interviews were held with those students who attended the examples class. The interviews were semi-structured in that students were asked to describe their experiences of using the audio-tape package and to comment on its benefits and drawbacks.

As usual, the examples class was poorly attended. Just 13 students had turned up. Hence it is important to note that these students comprised a 'self-selected' sample. Many of their comments duplicated those made on the questionnaire returns, although we were surprised by their emotive nature. Most of the students claimed they would have preferred lectures to the audio-tape package. They valued the opportunity to ask questions in lectures as and when problems arose, and they welcomed the external discipline enforced by the provision of scheduled lectures. Additionally, we found out that they valued the opportunity to interact with other students in the forum of a lecture. The simple act of attending a lecture helped them to focus on the material presented.

On a more positive note, many students enjoyed the control given to them to study the material at a time convenient to them. We thought it might be possible to exploit the notions of 'control' and 'ownership' in future when attempting to present the audio-tape package 'more acceptably' to students. These ideas are consistent with the concept that learner autonomy can be enhanced through 'metacognitive input' [13]. Ruddock [14] found that students tended to view teaching innovations negatively if they had not previously been exposed to a variety of teaching practices. She felt that most students preferred traditional modes of teaching and presented an inertia to change.

Project 2

A second attempt at using the audio-tape package in course ama248 was made in 2000/2001. Some amendments were made to the approach used in presenting the tapes to the students in light of the feedback from the previous academic year. The purpose of the audio-tape package was explained to the students at the beginning of the course. They were given a week to think about when they would prefer to receive the tapes and which lectures they were to replace. Some flexibility was possible as the five key topics of the course were self-contained. We hoped that by allowing them to take a more active role in the decision making on how this part of the course should be delivered, they might view the course more favourably than if they were essentially passive recipients.

The students requested that the audio-tapes be distributed at the earliest opportunity, so that those who wished to do so could make an early start on the material. They also requested that the tapes should replace the two lectures in week 6 (i.e. the week before reading week) and in week 12 (i.e. the last week of the course). As in the previous year, examples classes were held in those weeks in order to help the students with this work. Although the package nominally replaced lectures in week 12, many students said they would try to complete the work in week 6 and in reading week (week 7). We hoped that by collaborating with the students on the delivery approach to be adopted, more of them would attempt to complete the work during term time, rather than leaving it until the Christmas holidays. Examinations can be regarded as a major source of motivation in two ways: the need to achieve success; and the fear of failure. As the examination period draws nearer, the strength of this induced motivation increases! Another reason why we were particularly keen for the students to attend the examples classes is that they provide an excellent opportunity for the lecturer to encourage their attempts at mastering the new material. Positive feedback can serve as a powerful motivator for learning. As a further attempt to encourage the students to complete the work before week 8, we scheduled a short, informal test on the material in that week. We explained that the marks would not count towards the formal assessment but would help them to assess their own understanding of the work while there was still time to sort out any problems.

Analysis of questionnaire responses for Project 2

The audio-tape package was handed out in week 3. In week 8 of the semester (i.e. the week after reading week) a questionnaire was circulated in order to gain feedback from the students. In order to facilitate the comparison of results, the questionnaire was the same as that for Project 1. Out of a class of 50 students, 25 completed student questionnaires were returned.

It was encouraging to discover that, in Project 2, 13 students had worked thoroughly through the material, and that a further 12 had partially completed the work. No one admitted to not having looked at the material at all. Although there was still room for improvement, these results compared very favourably with the responses received from Project 1, when just two students had completed the work during the designated time. Students had spent longer working on the material in Project 2 than in Project 1. Nineteen students had attended at least one of the examples classes compared with just eight the previous year. Feedback suggested that the informal test had helped to focus students' attention on the topic of vector analysis. Over half of the replies from Project 2 indicated that the students thought that the audio-tape package adequately replaced four conventional lectures. Again, this compared very favourably with the feedback received from Project 1. Although the mathematical material was identical in both Project 1 and Project 2, in the latter case a special effort was made to win the students' support when the concepts of the innovation were introduced to them. They were invited to share the responsibility for deciding how the project should be implemented and, by so doing, we imparted to them a sense of ownership. We believe that it was this change in 'process' that led to the more favourable feedback.

Discussion

The process of encouraging our students to take an active role in deciding when and how the audio-tape package should be implemented in Project 2 appeared to increase their learner autonomy. They became more aware of the function of the innovation as an aid to learning and their reflections on this part of the course were more positive than those of the students who participated in Project 1. For most of the students the audio-tape package presentation was a new learning experience. Although it was designed to promote independent learning, the examples classes offered the security of a 'safety net'.

Eisner [15] discussed whether 'one of the greatest of educational fallacies is that the student only learns what he is being taught'. He highlighted the scenario that classroom life is complex and unpredictable and that consequently there is much more going on in a lecture than just the transfer of information. This offers some insight into the comment made by several students that they felt they were being 'short-changed' by the use of audio-tapes to replace lectures, as they missed the 'live' performance and opportunity for direct interaction.

Although innovations in teaching may aim to enhance students' learning experiences, this does not always occur. Even if careful attention is paid to the objectives, planning and implementation of an innovation, the outcomes achieved may not match prior expectations due to the complexities involved in the teaching learning process. 'Improvement' is itself controversial [16]. What is regarded as an improvement on the part of the lecturer or innovator may be perceived differently by the students forced to act as the 'guinea-pigs'.

Students appear to exhibit an inherent, cultural resistance to change. They tend to be comfortable with familiar teaching practices, and unless they are used to dealing with a plethora of different approaches they may react in a negative and even angry way to change. Although this initiative was teacher-directed, its principal aim was to enhance learner autonomy compared with the traditional lecture model. We explained to the students that we perceived the audio-tape package as offering a route towards more independent learning, but we became aware that this philosophy was not particularly appreciated by the students. Chan [7] wrote 'if the learner does not understand the reasons and benefits of autonomous learning, he/she may refuse the extra responsibility for and involvement in the learning process'.

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