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Teaching-learning environments and student learning in electronic engineering

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ABSTRACT

This paper presents early findings from the ETL project, a national study in Britain which is investigating teaching and learning across five contrasting subject areas in higher education. The focus here is on electronic engineering and, in particular on analogue electronics. Staff in six course units have collaborated with the researchers to enable data to be collected from their students, and in four of the units changes were made on the basis of the evidence presented to the them. The effects of these 'collaborative initiatives' were investigated using data obtained from the following year groups derived from questionnaires and interviews with both students and staff. On this basis, a clearer idea has been developed about the nature of teaching and learning in the subject with implications for ways of enhancing the teaching-learning environments provided for students in future.

INTRODUCTION TO THE PROJECT AS A WHOLE

The ETL Project

The ETL project (Enhancing Teaching-Learning Environments in Undergraduate Courses) is part of the UK-wide Teaching and Learning Research Programme of the British ESRC, and is now one of four projects (out of 31) focusing on teaching and learning in higher education. The programme is trying to strengthen the impact of educational research by requiring that each project is carried out in collaboration with 'users' of the research findings. In our project, these users are academic staff, but our findings will also be directed towards staff developers, institutional managers, and policy makers. The ETL project is exploring differences in the teaching-learning environments across four contrasting subject areas – biological sciences, economics, electronic engineering, and history. Within each subject area, staff in six or more course units across distinctively different institutional settings have agreed to participate collaboratively in our study over a two-year period.

In the first year, baseline data are collected. Staff are interviewed to allow the researchers to discover more about teaching and learning within the subject area, as well as details of the particular unit, supplemented by the documentation provided for the students. Two questionnaires were completed by students - one at the beginning and one at the end of the course unit. The first looked at students' reasons for taking the degree course and the course unit, and explored students' general approaches to learning and studying in the subject area. The second concentrated on the approaches used in the specific unit and about experiences of teaching and learning. Groups of students were also interviewed to explore those experiences in more depth.

These baseline data were then analysed and confidential reports provided for the staff teaching the unit. Discussions were then held to establish whether the feedback from students suggests there would be any value in developing a *collaborative initiative* designed to enhance certain aspects of the teaching-learning environment. Where such an initiative was agreed, the second year of collaboration involves the same data collection from the following year group to evaluate what changes in teaching and learning have occurred, and the extent to which these can be attributed to the collaborative initiative. Further details about the project can be found on the project web site – http:/www.ed.ac.uk/etl/publications.html

Concepts and measurements

Analyses of the feedback from students provided in the baseline data have been considered in the light of the notion of *constructive alignment.* Biggs (2003) has stressed the importance of designing curricula in higher education so as to ensure that, as far as possible, all the teaching-learning activities are aligned with high level (constructivist) aims. This formulation was developed partly from the student learning research to which Biggs has contributed and summarised, and partly from ideas from the school-based *Teaching for Understanding* framework produced by Project Zero in Harvard (Wiske, 1998). A particularly valuable aspect of that work was the use of *throughlines* representing high-level aims which are outlined to the students at the beginning of the course and repeatedly mentioned in relation to new topics as they arise.

Our project is concerned with helping staff to develop high-level learning outcomes, considered in terms of the *ways of thinking and practising in the discipline* which departmental partners suggested were most important in their course unit. This term was introduced to indicate the broad aims that seemed to underlie course development and assessment procedures in the department.

> *The ETL team coined the phrase 'ways of thinking and practising' in a subject area (WTP) to describe the richness, depth and breadth of what students might learn through engagement with a given subject area in a specific context. This might include, for example, coming to terms with particular understandings, forms of discourse, values or ways of acting which are regarded as central to graduate-level mastery of a discipline or subject area… WTP can potentially encompass anything that students learn which helps them to develop a sense of what it might mean to be part of a particular disciplinary community, whether or not they intend to join a given community in the future.* (McCune & Hounsell, in press)

We were then able to explore how the various teaching-learning activities were expected to fulfil those aims and expectations for student learning and also to consider to what extent the course units we examined were constructively aligned to those broad aims. The evidence that was collected and analysed is now described.

The conceptual framework

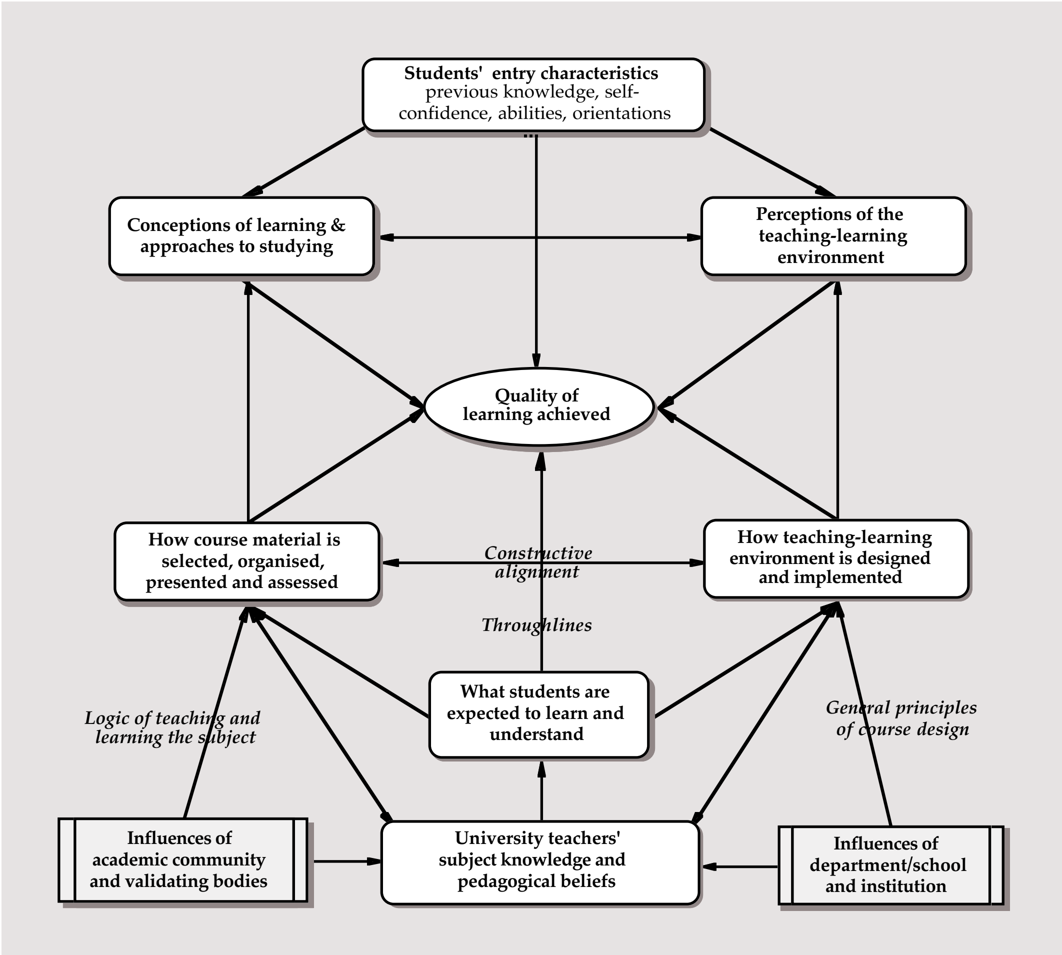
Although a wide range of disciplinary perspectives has been used in considering the nature of teaching and learning across the five contrasting subject areas in our project, Figure 1 indicates in broad outline the main concepts used in considering how various aspects of the teaching-learning environment are likely to influence the quality of learning achieved. Further discussion of this model has been provided elsewhere Entwistle (2003).

Collecting the base-line data

As already indicated, our data involve course documentation, interviews with both staff and students, and two questionnaires. During the first year of our collaboration with departments we collected the baseline data, against which the results of the collaborative initiatives to be evaluated. The *Learning and Studying Questionnaire* (LSQ) was given out in the first few weeks of each course unit, while the *Experiences of Teaching and Learning Questionnaire* (ETLQ) was completed towards the end of the unit. Both questionnaires contain sets of items that have been found to form coherent scales, although the analyses have also looked at individual items as well where these provide additional, more specific information. This set of variables was drawn from the set of concepts shown in Figure 1, but restrictions in the length of the questionnaires, and the time allowed with students, forced us to include only a subset of these. Those included will be described shortly.

Small-group interviews were carried out around the same time that the second questionnaire was completed to explore the students' experiences in more detail. A semi-structured interview schedule was used to

Figure 1 Concept map indicating influences on student learning



guide the focus of the discussions, but we also encouraged students to raise any other aspects that they felt were important; and that frequently happened. Transcripts of the interviews were produced and analysed, leading to an additional form of evidence that could be triangulated with the questionnaire findings.

Student entry characteristics

'Entry' here refers to the ways students see themselves in relation to the degree course as a whole, before they embark on the target course unit. The first two sections of the first questionnaire (LSQ) invited students to describe "What you expect to get from the experience of higher education" and "Reasons for taking this particular course unit or module". Both these sections drew on the distinction between intrinsic and extrinsic orientations to learning (Beaty, Gibbs & Morgan, 1997). All four aspects of intrinsic interest (academic, vocational, personal and social) held together under factor analysis to form a scale, but the extrinsic items remained separate. Prior knowledge, and confidence in it, was indicated by an item in the second questionnaire (ETLQ) which asked about the perceived demands of the unit in terms of "What I was expected to know to begin with". Students were also asked to rate themselves on their academic performance before beginning the unit, " based on the grades you have been obtaining".

Approaches to learning and studying First-year students in our sample were generally in the second semester of their course when they completed the questionnaires and so had sufficient experience to report on their studying. The third section of the LSQ asked students to describe their typical approaches to studying prior to starting the target course unit through a 36-item inventory developed from earlier inventories (ASI – Entwistle & Ramsden, 1983 – and ASSIST (Tait, Entwistle & McCune, 1998). The first section of the ETLQ used half the items to indicate the approaches to studying they had used in the course unit itself. Item factor analyses indicated five scales.

Deep approach involves a combination of intention and process, with items covering 'intention to understand' along with the associated thinking processes of 'relating ideas' and 'use of evidence' that parallel Pask's holist and serialist strategies (Pask, 1976). Additional items cover aspects of constructivist thinking, although these proved indistinguishable from those describing 'relating ideas'.

Monitoring studying combines items describing 'monitoring understanding', 'monitoring generic skills' and 'monitoring study effectiveness'. The first component is also related to the deep approach and is conceptually linked with self-regulation of learning processes and content (Vermunt, 1998).

Organised studying also includes time-management and overlaps the more general form of study regulation described by Vermunt.

Effort management indicates the amount of effort generally put into studying and also the ability to maintain concentration while studying, even when work is not particularly interesting.

Surface approach includes four aspects - 'unreflective studying', 'unthinking acceptance', 'memorising without understanding' (Meyer, 2000) and 'fragmented knowledge' (Meyer, 1991).

Experiences of the teaching-learning environment

The second section of ETLQ asks students about their experiences of teaching and learning in the unit, intended to cover the teaching and the more general teaching-learning environment. Factor analysis identified five main groupings of items.

Course organisation and management indicates how well the students recognised the main aims of the course unit, and how well organised the unit was perceived to be. Items also include the extent to which teaching and assessment aligned with the aims, as well as the amount of perceived choice of topics to study or the ways of doing that.

Teaching for deep learning includes items derived from the literature describing the types of teaching and learning activities related to 'constructivist' aims (Phillips, 2000) and likely to encourage a deep approach to learning. Crucial to this aspect is also the extent to which the assignments and assessments are believed to require using evidence and developing understanding. There are also items about the effectiveness of feedback in improving ways of learning and in clarifying what had not been fully understood.

Interest and relevance partly reflects the student's own interest in the subject matter ("I found most of what I learned in this course unit really interesting"), but also indicates a recognition of the teachers' efforts to make the content interesting and relevant.

Support from staff indicates the extent to which teachers were seen to have provided patient explanations, shown both enthusiasm and empathy, and valued students' views.

Support from students suggests how much mutual support and collaboration came from other students.

The third section of ETLQ asks about the perceived demands of the course unit and indicates how easy the knowledge and skills were perceived to be, as well as the rate at which new material was introduced and "the amount of work I was expected to do". And in two of the subject areas an additional group of ten items was added to cover specific aspects of the collaborative initiative.

The group interviews allowed us to interpret the questionnaire findings with more confidence and provided important additional insights into the course unit from the students' perspective. These were considered in relation to the scale scores and individual responses from the questionnaire and together generally have provided a strong indication of where a collaborative initiative might prove fruitful.

The collaborative initiatives

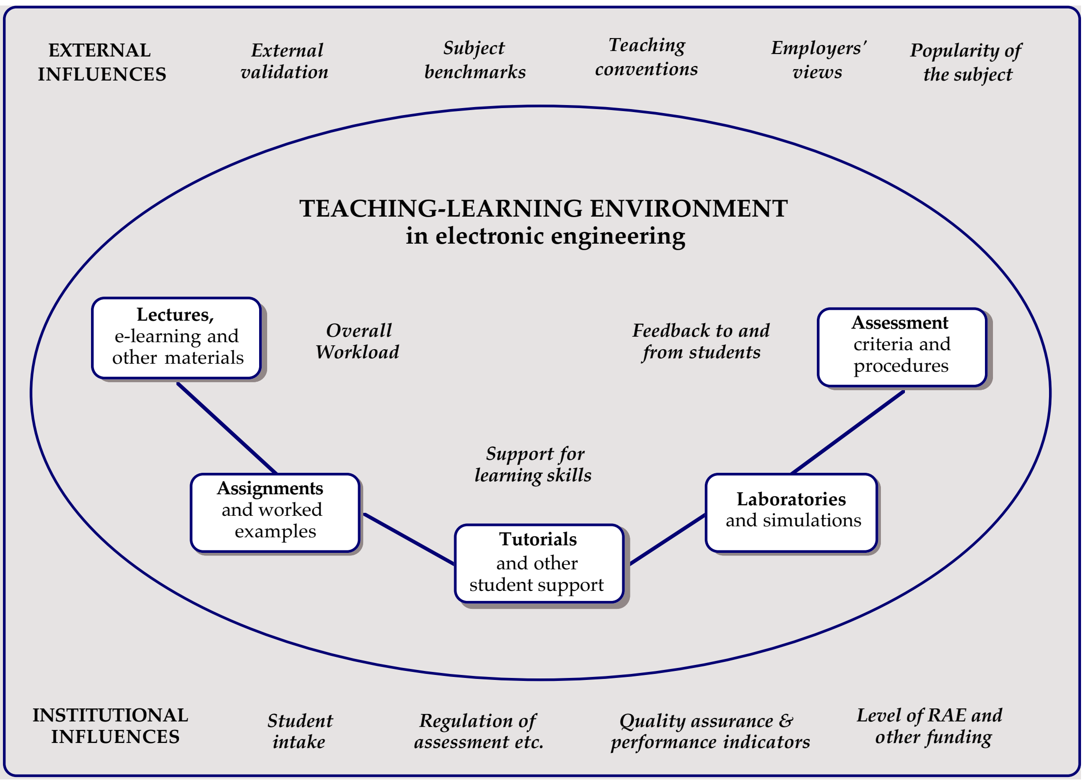
The baseline data collection provided a great deal of detailed information about students' attitudes, ways of studying and reactions to the course unit which could be amplified and extended through analyses of the group interviews with students. The scores on approaches to learning indicated the relative balance between deep and surface approaches adopted by students in the course as a whole prior to the unit, and also any changes in that balance in the target unit. Taking that evidence along with the questionnaire responses on students' experiences of teaching in the unit (both as scales and as individual items), and with the comments made in the group interviews, we were able to see if any aspects of the teaching-learning environment seemed to be out of line with the aims specified. Previous findings from student learning research could then be used in conjunction with an understanding of the course aims to suggest possible changes for the following year, which could then be discussed with staff. These discussions established whether a collaborative initiative would be feasible and acceptable and, where agreed, explored how best to implement it. This initiative was then introduced for the following year's intake of students and the same sets of data were again collected. Additional questionnaire items were also included with the second questionnaire in two of the subject areas.

TEACHING AND LEARNING IN ELECTRONIC ENGINEERING

Having established the overall research design of the project, we can now look at the research carried out within electronic engineering. Six course units were identified across four contrasting institutions. One was a first-year course unit on microprocessors in a city college, leading to the award of a Higher National Certificate with a small intake of students from industry on day-release. The next course unit was in a post-1992 university, a former polytechnic, which was preparing some 40 students through an Honours BEng for qualification as an Incorporated Engineer. The remaining four units were attended by larger classes of students in research-intensive universities, one was a 1960s university with particular strengths in applied technology, while the other was an ancient university covering the whole range of academic subject areas. Both the research-intensive universities were preparing students for the higher status qualification of Chartered Engineer. In all the universities the course units selected were on analogue electronics, the area being chosen because students generally find it difficult and there are concerns in industry about a lack of graduates with this specialism.

The ways in which teaching and learning of electronics were carried out all six course units were sufficiently to summarise within a single diagram (Figure 2) which also indicates the presence of other less immediate influences on learning within and outside the institution.

Figure 2 Teaching–learning environments in electronic engineering



The first analysis reported here is derived from the whole sample of students taking the six course units. Thereafter, the following two sections introduce the work carried out in the city college and the new university, after which the research in the remaining four settings is described more fully, as the larger samples make quantitative analyses possible.

Relationships between selected variables from the two questionnaires

Table 1 Factor analysis of scales from the two questionnaires for total and engineering samples

(N = 1970 undergraduate students for all subject areas; 365 electronic engineering students)

	Total sample				*Engineering sample*			
Scales ***Factor***	***I***	***II***	***III***	***IV***	***I***	***II***	***III***	***IV***
Entry characteristics								
Intrinsic orientation			.30				**.60**	
Extrinsic (vocational)								.23
Lack of purpose				.33				**.44**
Intrinsic reasons							**.45**	
Extrinsic reasons				.27				.32
Prior academic progress								
Self-rating on doing well previously		.22		—.25		**.41**		—.25
Prior approaches to studying								
Deep approach			**.96**				**.77**	
Monitoring studying		.28	**.52**				**.68**	
Organised studying		**.73**				**.53**	.28	
Effort management		**.71**				**.52**	.27	
Surface approach				**.98**				**.97**
Easiness of perceived demands								
Knowledge requirements	**.42**				.26	.36		
Skill requirements	**.42**				.29	**.42**		
Experiences of teaching								
Course organisation	**.78**				**.89**			
Teaching for deep learning	**.83**				**.80**		.21	
Interest and relevance	**.72**				**.68**			
Staff support for leaning	**.68**				**.70**			
Student support	.35				.28	.20		
Changes in approaches								
Increase in deep approach	.39		**—.53**		.23	.22	**—.47**	
Increase in surface approach	— .33			**—.54**	—.38			**—.56**
Changes in achievements								
Increase in knowledge	**.64**				**.59**			
Increase in skills	**.52**				.30	.33		
Academic progress in course unit								
Self-rating on doing well on unit	**.41**				.28	**.51**		
Inter-correlation between factors	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
I *Experiences and outcomes*	•	.29	.19	—.13	•	.29	.00	.00
II *Organisation and effort*		•	.22	— 11		•	.17	.00
III *Deep approach*			•	—.27			•	—.22
IV *Surface approach*				•				•

The four factors extracted 47.5% and 49.7% of the variance respectively. Loadings > .40 are highlighted; < .20 omitted

Table 1 compares the results of maximum likelihood analyses with rotation to simple structure of the total sample of students for both years of the study with those taking electronic engineering; these were the students who had completed both questionnaires. Four factors provided the clearest delimitation of the pattern of variation between the main components. Further subdivisions, although taking out an increased proportion of the variance, reduced the clarity of the main pattern.
The main purpose of this analysis was to test one of the main purposes of the project, namely that the provision of a teaching-learning environment which was organised to ensure constructive alignment and taught so as to promote understanding would lead to higher achievement and deeper approaches to studying. All the scales derived from the two questionnaires were included, with the addition of two items to cover a vocational extrinsic orientation and a feeling of a lack of purpose in being on the course. In addition, two additional scales were created by subtracting the score on the deep approach prior to the beginning of the unit from the deep approach adopted during the unit itself. (10 was added to this difference score to avoid minus signs.)

The first factor has an identical pattern for both the total sample and electronic engineering. It describes positive perceptions of the teaching and learning experienced on the unit with increases in deep approach and decreases in surface approach. It also shows substantial loadings on the self-ratings on knowledge, skills and doing well on the unit. The second factor is defined in the total sample almost entirely in terms of organised studying together with effort and concentration. In the engineering sample, however, the factor also shows substantial loadings on self-ratings on skills and doing well both before and during the unit. It also suggested links with perceived easiness of the demands made by the course, as well as an increase in deep approach and support by other students. The final two factors describe deep and surface approaches linked to intrinsic and extrinsic reasons for being in higher education, with surface also being quite strongly linked to a feeling of a lack of purpose among the engineering students. The negative relationships with changes in the approach suggest that students with high scores on either deep or surface are more likely to decrease their scores, but this is presumably an artefact created by regression to the mean.

Having looked at overall relationships, the next step is to look at teaching and learning in five of the settings in which we have been working. The first two are essentially case studies, using mainly the interview data to describe the context and the experiences of students. In the space available, it is impossible to explain the way in which these main findings were rooted in the qualitative analyses, but full descriptions have been published elsewhere. The first of the case studies looks at a city college in which electronics is taught at an introductory level. All the other settings involve the teaching of a specific aspect of the degree course - analogue electronics - and so, before looking at the second case study, we need to discover what staff and students said about the ways of thinking that are required in that sub-area of the subject. After describing the second case study, analysis of the four remaining settings taken together, are presented making use of the inventory data, as well as the interviews.

Introduction to microprocessors in a city college

The first case study is a summary of an earlier publication (Bromage & Whitaker, in press). It describes work which looked at a first year module of an electronic engineering on a course leading to a pre-degree level award (HNC). The module tutor characterises its main focus as using microprocessors in problem-solving systems. During the first 'baseline' year cohort of ten students were aged between 17-19, most on 'day release' from electrical maintenance in industrial settings and progressing from a two-year National Diploma. In the 'follow-up' year, the cohort of eleven students was similar in character.

The module tutor's insight into 'baseline' teaching and learning issues was sound; analysis of the data collected in the course of the ETL project tended to confirm and elaborate on them. The central issue, the module's 'perceived relevance', cut across several interrelated, aspects, 'teaching and learning activities', 'ways of thinking and practising in the discipline', 'core and threshold concepts', 'set work and assessment strategies', 'learning resources and support materials', 'the influence of the academic community and validating bodies' and 'students' perceptions of the learning environment'. Two further issues, 'learner independence' and 'social relations and support' invoked relationships between 'student engagement', student independence' and 'tutor feedback'.

The central issue was traced to the equipment deployed in the module and it's alignment with technologies visible in the students' occupational milieu. Arguably, a precipitating factor was their colleagues' minimal understanding of what the students had learned or why. The influence of this 'community of practice' (Wenger 1999) apparently precipitated a 'crisis of confidence' or 'intellectual isolation' in the 'baseline' students. Their occupational milieu emphasises the practicalities of 'engineering technologists', whereas the occupational model built into the module is arguably of the 'holistic professional engineer' (Robinson and Bramhall 2001).

The agreed intervention
In the 'Baseline' year, learning activities featured the obsolete Z80 microchip, which has similar architecture to recent chips, and BECCA-plus single-board computer, which lacks user-friendliness. The students consequently expended much time and energy mastering the equipment, a 'core concept' aspect, and this arguably sapped their enthusiasm and confused them as to the module aims.

Their perceptions influenced the tutor, who sought to introduce the Programmable Interface Controller (PIC), a user-friendly update on the Z80 featuring enhanced functionality. The students were anticipated to master the equipment faster, facilitating a shift in emphasis from 'core concepts' towards 'ways of thinking and practising', using microprocessors to solve problems, through project-based learning. The approach was anticipated to foster independent learning. The 'baseline' module was largely tutor-led, albeit with some hands-on programming. Project work shifts the balance towards student-centred working, with 'tutor-led' provision of background resources.

The baseline year assessment, undertaken during the module's second half, comprised two reports on 'peripheral equipment' and a three-hour written exam. The follow-up session featured project-based assessment with timetabled formative feedback, in-class discussions on learning activities with tutor feedback. However, the follow-up cohort called for a 'whole class' approach, as individual student's problems tended to dominate the sessions.

Responses to the collaborative initiative
The changes made in the follow-up session depended upon replacing the Z80 with the PIC processor system. This highlights how available facilities tend to condition and constrain teaching and learning possibilities. The baseline cohort had complained about BECCA-plus from the start, and saw the module as 'too theoretical'. The follow-up cohort had no complaints about the PIC-based single board computer. The follow-up year featured greater alignment between the visible technologies deployed in the module and those in the in students' workplaces. However, several students expressed similar reservations to their predecessors. It is arguable that is the role of abstract theory in the working practices of the 'holistic professional' may be the main 'threshold concept'. Introducing the PIC processor enabled the tutor to 'network' with the academic community, in particular Smith (2002), who has developed a PIC-based computer and associated learning activities. Wider possibilities include using the PIC in distance learning, as discussed by Hett and Schubert (2003).

Ways of thinking in analogue electronics

In our initial discussions with staff and interviews with students, we began by exploring the nature of topics within analogue electronic engineering. Previous research had suggested that one of the specific difficulties students encounter in electronics is that they are faced with contrasting representations or models of a circuit – the actual circuit, the circuit diagram, simplifying transforms of it, algebraic solutions, and computer simulations (Entwistle *et al.*, 1989). Students have to move between these different representations in solving problems or designing circuits and they also need to understand the function of a circuit in both practical and theoretical ways – the engineering applications and the physics of how it behaves.

In analogue electronics, one additional difficulty seems to be that understanding involves both analytic skills and an 'intuitive' grasp of circuit characteristics - intuitive in the sense that the characteristics of analogue circuits are less transparent and predictable than digital ones. Students thus have to build up substantial experience of the properties of many different kinds of circuit before they can 'see' what lies behind any new circuit diagram they meet or can decide what type of circuit will be required in a design problem.

Understanding electronic circuits thus involves a combination of intuition derived from experience, detailed analysis using problem-solving skills that involve algebraic knowledge and dexterity, and imagination in designing new circuits. This combination of skills, not surprisingly, creates more difficulty than other areas of the curriculum. Staff and students alike explained that a rather different way of thinking was required for analogue compared with digital, one which many students initially found it more difficult to acquire. As one undergraduate student commented:

> *I think it requires a different kind of mindset than digital, which seems to be more to do with computer science. For analogue, I think it is much more mathematical and analytical. Even just a little difference in a circuit can make a big difference to how it operates, so you have to realise that and go back to first principles and work out how it works again.*

Final-year analogue electronics in a new university

The main focus here is on staff and student perceptions of the teaching-learning environment in a final-year unit. Unusually, all of the teaching is delivered by one lecturer with responsibility for analogue electronics throughout the three years of the degree. Analysis of students' responses to our second questionnaire (ETLQ) indicated a high level of satisfaction with their experience of teaching and learning in the unit. The lecturer was perceived as having made the subject more interesting and having provided more examples than was the case in other units. The assessment had been made clearer, with good feedback on set work. Students also felt more confident about their knowledge and understanding. Interviews were also carried out with the lecturer and two groups of students, to explore their perspectives in greater detail.

The lecturer's perspective

The lecturer had considerable experience both in HE teaching and in industry. In his interview comments he emphasised the practical nature of the degree, together with the coherence, continuity and increasing complexity of the teaching and learning over the three years. Asked what he wanted the students to get out of the course, he emphasised the importance of teaching for understanding. He described how he tried to keep things simple, particularly with the maths, using repetition to promote understanding and drawing on a mixture of methods to encourage active participation, including gapped notes and diagrams. Above all, he emphasised the importance of hard work for the achievement of real understanding. He actively looked out for evidence of understanding, for example from his continuous assessment of laboratory work. He openly acknowledged that his approach was determined both by the changing nature of the student intake and a reduction in class contact time. He described his approach as one that started where the students were and led them gradually towards increasing confidence and self reliance. He also highlighted the influence of the lecturer in the encouragement of student learning by his own approach and behaviour towards students: conveying his own enthusiasm; being approachable and available outside timetabled classes; and being well organised and prepared.

The students' perspective

Frequency distributions of items from the second questionnaire showed a high level of satisfaction with the experiences of this course unit, and this was supported by the student interview data. Those interviewed were particularly appreciative of the lecturer's organisation, approachability, availability, patient explanation and general supportiveness, all of which were perceived as having positive benefits for learning. Asked how they went about learning analogue electronics, students described a particular way of thinking that depended on memorisation for understanding, especially with regard to mathematical equations. In terms of doing well in analogue, they demonstrated awareness of their own responsibilities as learners in terms of maintaining interest and enthusiasm and putting in the work. This, they felt, was particularly important given that analogue continued throughout the three years of the degree, unlike other one-semester units where 'you never look at it again'.

The students also talked about the incremental nature of the subject, how it built on learning and knowledge from previous years and the importance of mastering the 'building blocks' and keeping up with the work. Another aspect referred specifically to the importance of learning how to apply the theory; demonstrating applications to the world of work; learning to think like a professional engineer. Some would have liked even more in the way of practical application, seeing the skills they were developing as related mainly to academic theory rather than to professional practice. Students who had done a placement year were enthusiastic about their experience of placement and emphatic that the course theory and concepts should be even more closely linked to applications met in industry, with more practical, hands-on experience. They also referred specifically to the benefits of the placement experience when tackling their final year project and to the positive motivational impact of the placement on their approach to their final year studies.

To sum up, both lecturer and students commented on the perceived advantages of continuity, coherence and connectedness over the degree programme as a whole. While this stemmed here from the unusual situation of having one lecturer teaching analogue electronics throughout the degree course, it does at least raise the issue of how best to ensure such coherence, given the growing recognition of the difficulties which students experience within a modular system without built-in connections between modules.

Analogue electronics in the two research-intensive universities

The next step is to look at the two research-intensive universities, starting with the methods of teaching and learning that were used across all the course units. We then draw mainly on the questionnaire data to examine differences between the three of the units in which collaborative initiatives were carried out, considering items which brought out these differences most clearly and, in particular, the approaches to studying that students reported carrying out before the unit started and during the analogue unit. We then consider the teaching-learning activities which students mentioned as being most helpful in their learning in these units, or making it more difficult. These analyses formed the basis of suggestions for the collaborative initiatives carried out, with the reasons for them being explained. Finally, we shall examine the way the initiatives were implemented and how students reacted to them.

Teaching and learning in the four settings

There was substantial similarity between the two departments in how the skills in thinking about analogue circuits were developed. Lectures introduced the theoretical ideas underlying various types of analogue circuits, their functions, and the analytic procedures involved in calculating the expected outputs from those circuits. Students were expected to work through a substantial number of circuit problems to build up the ability to recognise the component parts of circuits which combine to produce effects on the input to the circuit. Work on these examples was done partly by the students independently and partly during group tutorials or ‘examples classes’ where help was provided by the lecturer or tutor. Assessment was based entirely on end-of-unit examination, except in one unit where some course work also counted. Students obtained rather little individual feedback on work handed in, although general pointers were provided on performance in class tests and all course units offered some worked examples through which students could check their own solutions. Laboratory experience was provided within a separate unit in the second-year courses, but it covered all the course units being taught at that time, with no direct match possible with topics being taught in the lectures. It was intended that students who attended the classes and completed the work would have a sufficient grasp of the topics to be successful in the end-of-unit examinations, but failure rates proved disappointingly high at the first sitting in all three units during the first phase of the project.

Although the types of teaching and the assignments were very similar across the three units, interviews with the staff suggested that there were marked differences in the way they thought about the subject, and those were, to some extent, reflected in the teaching. Staff who had substantial experience of working in industry were more likely to explain circuits in a functional manner, emphasising design aspects, while other lecturers brought the logical structure of the topic area to the fore, stressing the physical and analytic aspects more strongly. Thus, the teaching of analogue electronics varied in the relative prominence given to analysing existing circuits in mathematical detail and to considering how circuits could be designed to achieve required outputs. There seemed to be no disagreement about the need for both ways of thinking, but the balance between the analytic and the functional does seem to affect how students perceive the subject.

> *When you’re sitting and learning in class you tend to be doing circuit analysis and looking at equations whereas when you do anything in the real world or in the lab, you want to go in exactly the reverse direction. You want to take an idea and figure out how to implement it rather than have an implementation and figure out how it works… It’s in the final stage, when you’ve already put all this effort and all this design and time into a circuit, you know that the analysis, no matter how hard it is, has to be done.*

During the first year of our collaboration with departments, we sought to discover which aspects of the teaching students found most helpful, and which learning had proved most difficult for them. Students generally appreciated the overall quality of the teaching and the efforts that staff were making to help them to understand. Although students expected to find analogue interesting, they did not expect it to be easy; and that was their subsequent experience. In both second-year course units, a substantial proportion of the students reported aspects of analogue to be difficult to understand and suggested ways in which they might be given more support through the teaching arrangements. There was also a more general feeling about the 'sameness' of their learning experience that became de-motivating over time.

[In the learning, you're repeatedly] reading it, hearing it, talking about it, doing it, doing it, doing it… Personally for me that system doesn't work. And I don't know, I guess that's probably why, for first, second and part of third year, it was a case of scraping by. Except for in the case of projects, I've tried to go through the motions; it's the sameness. It's [the same] pattern, and each day is that pattern.

Comparisons between course units

Besides knowing how the items and scales interrelate, it was also important to consider differences between the three units on all the main aspects included in the first year of the work with departments. To make clearer what students were actually rating, individual items have been used throughout Table 2 which presents two kinds of comparison. For most of the items, straight comparisons are made between the three courses – two second-year courses and a smaller third-year unit. But the items describing approaches to studying introduce comparisons between the ways students said they were studying before starting the analogue unit and how they studied during that unit. (As these items are derived from well-established general scales, the wordings do not necessarily fit ideally with specific study activities undertaken in electronic engineering, but students do seem to be able to interpret them within that context.)

Looking at the ways students described how they were studying before and during the unit, we find that in Courses A and B the students' approaches during the unit were less deep, less organised and more surface, than their general approaches reported at the beginning of the unit. In Course C, however, the first deep item (which provides the clearest indication of a deep approach) suggests a deeper approach in the unit than beforehand, and that is reinforced by a reduced level of surface approach in both those items.

In all three course units, students reported putting in less effort than in other units and, from the frequency distributions of individual questionnaire items, it seemed that about a quarter of students in each of the second-year classes had probably failed to put in the time and effort required to master the techniques. Some of the students indicated in the interviews that they had been deterred by the initial difficulty and so adopted 'surface' coping strategies, rather than engaging with the problems in ways that would lead to understanding. As one student commented:

You work through the tutorial problems and, for the analogue ones, you don't get any answers out of them. You … sit down and work through the problems and realise you've done all of them wrong … and you can't see how in the world you got from point 'a' to point 'b'… I tended to [work] blindly. I knew if I [just] followed these steps, then I could come to an answer… We can teach ourselves … to do an example and have no idea what to do and we scrape by. But we probably would have got great marks had we actually understood what we were doing.

Students need to be convinced that the effort they have to put in is worthwhile and that they will be able to reach solutions to a reasonable proportion of the examples set.

In other research on electronic engineering students, Scheja (2002) suggested that they had experienced *delayed understanding,* as a result of which they felt they were falling behind in their studies and used a variety of coping ploys to try to catch up. Students in our own study made comments that suggest a similarexperience. Of course, some delay in understanding is to be expected, but in this subject area it seems to be substantial. One second-year student commented:

In second year I got a better understanding of what I learnt in first year. Now in third year I've kind of learnt what I was supposed to know in second year. It's a shame that I've never felt that I've learned it in the actual year [it was taught]… When you're being taught something, you're just desperately trying to learn it, and there's not necessarily a whole lot of interest. You're scrambling back to notes [in preparing for the exams], trying to understand the course. [Later on], you do get interested and [then] things start to fall into place.

TABLE 2 Percentage agreement with items by questionnaire and course unit

		Second year		*Second year*		*Third year*	
Scales and items		***Course A***		***Course B***		***Course C***	
Number of students competing first/both/second questionnaires		(N = 94/68/75)		(N = 68/40/49)		(N = 54/32/40)	
Attitudes towards the degree course							
I want to study the subject in depth		87.2		77.9		61.1	
I sometimes wonder why I ever decided to come here.		5.2		14.7		29.6	
Relative <u>easiness</u> of demands made by course unit							
What I was expected to know to begin with.		65.3		71.4		62.5	
The rate at which new material was introduced		25.3		46.9		72.5	
The amount of work I was expected to do		33.3		34.7		52.5	
Approaches to studying		*before*	*during*	*before*	*during*	*before*	*during*
I usually set out to understand what we had to learn	*deep*	95.6	72.1	87.5	82.5	81.2	75.0
I look at evidence carefully to reach my own conclusion	deep	75.0	57.4	67.5	50.0	31.2	43.7
I've often had trouble in making sense of the things	surface	25.0	61.8	40.0	55.0	43.7	34.4
What I've learned seems unrelated bits and pieces…	surface	11.8	23.5	25.0	32.5	40.6	9.4
I have generally put a lot of effort into my studying	effort	60.3	51.5	77.5	60.0	53.1	40.6
I'm quite systematic and organised in my studying	organisation	65.9	44.1	62.5	47.5	46.9	50.0
Experiences of the teaching provided in the course unit							
How this unit was taught fitted in with what we were supposed to learn.		72.0		67.3		97.5	
I could see the relevance of most of what we were taught in this unit.		78.7		79.6		95.0	
I found most of what I learned in this course unit really interesting		45.3		34.7		82.5	
Plenty of examples illustrations were given to help us to grasp things		66.7		51.0		95.0	
Staff tried to share their enthusiasm about the subject with us.		89.3		91.8		100.0	
Staff were patient in explaining things which seemed difficult to grasp.		81.3		81.6		92.5	
Staff gave me the support I needed to help me complete the set work		69.3		51.0		75.0	
The feedback given on my set work helped to clarify things		63.7		30.6		47.5	
Talking with other students helped me to develop my understanding		81.3		71.4		72.5	
Students supported each other & tried to give help when it was needed		81.3		73.5		85.0	
Self-ratings of learning outcomes							
Knowledge and understanding about the topics covered		73.3		69.4		92.5	
Ability to think about ideas or to solve problems		77.3		71.4		92.5	
Skills or technical procedures specific to the subject		70.7		61.2		95.0	

Approaches to problem solving

Students interviewed generally agreed that they were, at first, not at all clear how to solve tutorial problems. They were looking for clear strategies to be offered within the lectures that would guide them more easily towards the solutions. They also wanted more worked examples to be provided to offer additional guidance. Although recognising that worked examples could be helpful, staff were wary of too much 'spoon-feeding' in case it encouraged the mindless following of routines. As we have seen, both staff and students agreed that there was a way of thinking associated with the analysis of analogue circuits that had to be mastered, but achieving this competence proved difficult for a substantial proportion of the students. The marked tendency for surface approaches to be adopted made understanding less likely. It therefore seemed sensible to concentrate our collaborative initiatives on helping to make students more consciously alert to the ways of thinking that were involved, and to explore the reasons for the difficulty experienced more fully in the second year of the work with departments. The initiative agreed was based thus based on the evidence collected in the first year of the collaboration, but also on the more general research on student learning and psychology.

Expert and novice learning

There is a substantial research literature in psychology on how novices differ from experts in the problem-solving skills required in employment settings, and how such skills can best be developed (Sternberg, Grigorenko & Ferrari, 2002). Although problem-solving in electronic engineering clearly has aspects which are specific, there should still be elements in common with professional contexts. The main features highlighted in this psychological research were found in the teaching of analogue electronics, although not always in a fully developed form.

All the units gave students a large number of examples chosen to cover the most salient differences in the problems, but novices also have to be encouraged to look for recurring patterns and to develop systematic strategies. While students asked to be given clear guidelines for solution strategies, lecturers were aware of possible pitfalls. They wanted students to realise that mindless following of such guidelines would not get them very far in analogue electronics. The psychological research suggests that, in the early stages, novices do need the 'scaffolding' provided by set routines or strategies, with that support gradually being removed as students develop in experience and confidence.

> *The metaphor of scaffolding is appropriate because scaffolding is an external structure that supports another structure under construction. As the new structure is completed and capable of standing on its own, the scaffolding is removed (McCormick & Pressley, 1997, p. 15).*

Hearing experts solve problems out loud is also important for novices, as it makes explicit the ways of thinking used by them in reaching solutions: staff did this quite regularly but students wanted rather more of this activity. And discussions about problem-solving processes and more generally in learning, both in engineering (Nicol & Boyle, 2003) and in other subject areas (Biggs, 2003). Students we interviewed had generally not been given such opportunities in class, although some of them had formed self-help groups in their own time. Finally, the research suggests ways of encouraging novices to internalise their reasoning processes, for example, by making notes about mistakes made and better ways of tackling the problems. Some students seemed to be doing this, but others were not working so systematically.

The collaborative initiatives

All the teaching staff agreed to explore ways of encouraging more students to use a deep approach by focusing explicitly on the processes and strategies of problem-solving. Besides putting a strong emphasis on explaining the processes in lectures and tutorials (as was already happening), it was decided to introduce other student activities during the second year of the collaboration.

As a way of encouraging students to think more consciously about problem solving, students were asked to carry out their work on problems in a tutorial 'log-book' which staff could look at during tutorials. They were encouraged to note down corrections to their attempted solutions in ways that would draw attention to where they had gone wrong, and what they should have done. Besides making their thinking explicit, the log-book also drew their attention to the need to build up a substantial number of solutions there. It was also agreed, where possible, also to get students to work together in small groups to discuss the problem-solving processes both in classes and in their own time.

Implementing the initiatives

In the event unexpected difficulties prevented a full implementation of the initiative in two of the units. The start was substantially delayed in Course A due to a prolonged illness of the lead lecturer, and was only used for a short time in Course B; however, it was fully implemented in Course C. Questionnaires given at the end of each unit contained additional questions specifically about how much the students believed that the various teaching-learning activities on the unit had contributed to their learning and understanding. In addition, students were asked to add their own comments about what helped and hindered, and these will contribute to the eventual conclusions.

Table 3 shows the mean and standard deviations on seven-point scales for the samples obtained in the collaborative phase of the project, indicating how much each of the aspects was believed to contribute. The data were collected within lecture periods with inevitable variations in the nature of the samples obtained. There seemed little point, therefore, in carrying out tests of significance. The differences have thus to be seen as simply indicative, and used in conjunction with open-ended written comments and interview data to draw tentative conclusions.

Unit A was perceived by the students responding as being very strong in the provision of worked examples and in enabling students to work on problems on their own, supported by effective help in tutorials, although the explanations in lectures were rated less highly. Unit B was almost the converse, with the explanations appreciated, but worked examples and the tutorial help less highly regarded. There was considerable variation in the rating of tutorials in this unit, however, as students from different degree courses (such as mechanical engineering and computing) reported contrasting experiences. In neither unit was the feedback on work submitted felt to be very helpful, and that seems to have been a general reaction from students across most of the units we have looked at. These views were also expressed in the interviews.

TABLE 3 Mean scores of ratings of relative helpfulness of teaching-learning activities

Teaching-learning activity	**Mean scores on a 1 – 7 scale** **Course A** **Mean (SD)**	**Course B** **Mean (SD)**	**Course C** **Mean (SD)**
	N = 59	N = 73	N = 27
The way diagrams presented	5.0 (1.3)	5.3 (1.2)	5.9 (0.6)
The way ideas explained in lectures	4.3 (1.6)	5.6 (1.2)	5.2 (0.8)
Lecture explanations of problems	4.2 (1.8)	5.8 (1.3)	4.9 (1.1)
Worked examples provided	5.0 (1.4)	3.6 (2.1)	5.7 (1.1)
Working on problems on own	5.2 (1.3)	4.6 (1.5)	5.3 (0.9)
Using the log-book	4.2 (1.7)	4.3 (1.5)	5.1 (0.9)
Staff help in tutorials	5.0 (1.7)	4.0 (2.3)	5.9 (1.1)
Discussions with other students	4.8 (2.1)	4.7 (2.0)	5.0 (2.0)
Feedback on work submitted	3.5 (2.1)	3.6 (2.2)	2.6 (2.4)
Class tests and the results	4.3 (1.8)	4.2 (1.9)	not given

TABLE 4 Items defining three factors related to aspects found helpful in learning analogue

Items are presented in the order of the size (above 0.35) of factor loadings within each set of items

Well-organised teaching providing good explanations, examples, emphasising thinking

Items on what helped in learning analogue
The way the lecturer(s) explained how to think about problems
The way ideas and concepts were explained in the lectures
The way diagrams were presented and used in lectures

General items relating to experiences of teaching and learning
Staff helped us to see how you are supposed to think and reach conclusions in this subject
Staff tried to share their enthusiasm about the subject with us
We weren’t just given information; staff explained how knowledge is developed in this subject
The course unit was well organised and ran smoothly
The teaching encouraged me to rethink my understanding of some aspects of the subject
We were given a good deal of choice over how we went about learning
How this unit was taught fitted in well with what we were supposed to learn
Plenty of examples and illustrations were given to help us grasp things better

Supporting students’ work on tutorial examples

Items on what helped in learning analogue
The help give by staff as you worked on tutorial problems
Feedback and comments from staff on the work submitted
Worked examples provided in handouts or on the web
The class tests and the results you were given
Working on the tutorial problems on your own

General items relating to experiences of teaching and learning
The feedback given on my work helped me to improve my ways of learning and studying
Staff gave me the support I needed to help me complete the set work for this unit
The feedback given on my set work helped to clarify things I hadn’t fully understood
The different types of teaching (lectures, tutorials, labs., etc.) supported each other well
On this unit, I was prompted to think about how well I was learning and how I might improve
Doing the set work helped me to think about how evidence is used in this subject
I was encouraged to think about how best to tackle the set work

Working collaboratively with other students
Items on what helped in learning analogue
Group discussions with other students on doing the problems

General items relating to experiences of teaching and learning
Talking with other students helped me to develop my understanding
Students supported each other and tried to give help when it was needed
I found I could generally work comfortably with other students on this unit

The use of log-books was the main innovation in the teaching in all three units and it was hardly surprising that students rated that activity highly only where it had been fully implemented. In the interviews, reactions to the log-books varied. Initial reservations about an additional task were expected, and found, but there were also positive comments. Students appreciated having all their workings together and found their own comments helpful when reviewing their workings.

Some students also found that they had become more aware of the need to keep up with their work in preparing for the tutorials. A typical comment was:

> *I got used to writing down all the problems in the log-book and then you can sort of look back and read through it and understand what you have done… At first I'd just look at a couple of tutorial questions and write down what I thought. But now I've got, like, pages of stuff written down, so I think the log-book now is really important to my understanding.*

It was clear, however, that students did not appreciate being told precisely how they should use the log-books, as they develop a way of using them that is coherent with their established ways of studying. And some students had found it difficult to know what type of comments to make: reflection on learning processes does not come naturally and so requires a thorough introduction and substantial help until the idea has been fully grasped.

Teaching to enhance learning

The final analysis to date brings us more directly to the main aim of the project – to identify ways of enhancing the quality of student learning. This analysis has brought together all the items in the second questionnaire used to report students' experiences of the teaching with the additional items specific to electronic engineering (N =129). Three of seven factors extracted described the main differences among the**specific items, and these were linked to a sub-set of the general items. The combination of the two groups of items within each factor helps to suggest what aspects of the teaching-learning environment in analogue electronics students found most helpful in supporting their learning. The items picked out by these three factors are shown in Table 4. The first group of items describes teaching that is perceived by the students to be coherently organised and which is seen as providing good explanations and examples, emphasising the need to think more deeply about the subject. The second group indicates the types of support that students appreciated in working on the examples, while the third suggested the ways in which collaborating with other students had helped.**

A tentative suggestion emerging from an overview of the analyses to date is that there are some aspects of the teaching and learning that are more directly, even logically and inevitably, related to the nature of the subject bring taught, while others derive from more general pedagogic considerations. While this analytic separation seems worth exploring further, the reality is unlikely to allow clear-cut divisions and may well differ between contexts. At the current stage of our analysis certain aspects do seem to be logically essential for students to develop an understanding of analogue circuits, while others play a more supportive role in making the students' work easier and more enjoyable. Only if the logically necessary components are well developed, and sufficient of the supportive elements are present, will students report substantial satisfaction with their experience and find it relatively easy to develop their understanding. And, if substantiated, this conclusion will probably apply generally in the teaching of electronics, and possibly in other disciplines.

Looking, finally, at the project as a whole, it is demonstrating the value of using detailed feedback questionnaires, together with group interviews, to describe students' experiences of teaching. In this way it becomes much clearer which aspects of the teaching-learning activities are most appreciated by students as supporting their learning, and interpreting those findings in relation to the explanations provided by staff suggests ways in which current provision may be strengthened. At this stage of the project, these elements in teaching and learning electronics are only gradually becoming clear through the ongoing analyses of interview transcripts. Bringing together the whole set of analyses, and looking at these in relation to the other subject areas, should enable us to describe more clearly what is specific to teaching and learning in those disciplines and professional areas.

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