

An evidence-based approach to designing a first year Electrical Engineering Course

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Structured abstract

BACKGROUND

This paper investigates a new first year Electrical Engineering course which has been designed with a view to aligning with the evidence on what facilitates student achievement. To this end, the course has been designed to exploit those factors which, according to the evidence, have the highest effect sizes on student achievement. The evidence has been compiled by analysing the findings from over 800 meta-studies on student achievement (Hattie, 2009). The analysis indicates that the eight factors which have the highest effect sizes (and which are pertinent to higher education) are (i) formative evaluation, (ii) microteaching, (iii) acceleration, (iv) teacher clarity, (v) comprehension fostering via cognitive strategy scaffolding, (vi) feedback, (vii) teacher-student relationships & (viii) spaced practice.

PURPOSE

The research question investigated was whether or not a course designed to exploit the eight above-listed evidence based factors would produce improvements relative to traditional modes of learning. Specifically, the investigation targeted improvements in three key areas, namely (i) student satisfaction, (ii) student achievement, and (iii) student interest in Electrical Engineering.

DESIGN METHOD

To measure student satisfaction, conventional university student satisfaction instruments were used. These scores were compared with other similar first year university courses. To measure student achievement, performance was compared between a test group (which elected to participate strongly in the newly designed learning initiatives) and a control group (which elected not to participate strongly in the newly designed learning initiatives). To measure student interest in Electrical Engineering, student selection rates for second year Electrical Engineering before and after the introduction of the new course were compared.

RESULTS

The new course has been found to have high student satisfaction compared to other similar courses, and the course has been found to coincide with increased popularity of Electrical Engineering as a chosen discipline in second year. Student achievement has also been found to be significantly higher among students who elect to engage with the newly designed course initiatives.

CONCLUSIONS

The new course design initiatives have coincided with high student satisfaction ratings, increased popularity of Electrical Engineering and increased student achievement. These findings augur well for future designs based on evidence from meta-meta-studies such as the one in Hattie, J. (2009).

KEYWORDS

Evidence-based practice

Introduction

In 2012, the first year Bachelor of Engineering program at the University of Queensland was restructured with an overarching goal of providing a more multidisciplinary first year experience (Fyeuq, 2013). This included the development of two new compulsory courses and the redevelopment of courses in key engineering discipline areas. In Electrical Engineering, the previous course "Introduction to Electrical Engineering" (ELEC1000) was superseded by the new "Introduction to Electrical Systems" (ENGG1300). As with the previous course, ENGG1300 aims to provide entry level coverage of Electrical Engineering concepts for students who will continue with Electrical or Mechatronic Engineering. In addition, it also aims to serve as an effective terminating course for students of other disciplines. This course is compulsory for Electrical, Software, Mechatronic and Mechanical Engineering students, and is an elective for students of other Engineering disciplines, with approximately 75% of all first-year Engineering students taking the course in 2012.

In addition to the change in content associated with the aims of the new course, the course redevelopment was used as an opportunity to structurally implement evidence based teaching practice to achieve improved learning outcomes for the students (Hattie, 2009). This paper thus aims to: (a) present this course as a case study to illustrate how evidence based practice was incorporated into the course structure; and (b) evaluate the effectiveness of this new course structure with respect to student achievement, student satisfaction and impact on selection of Engineering discipline in second year.

Design Rationale

A number of major reviews have been undertaken of the evidence on how people learn. Some of the best known reviews within the engineering education and wider domains are (Bransford et al, 2000), (Hattie, 2009) and (Felder, 2012). These works have produced similar key findings – factors such as practice, feedback, challenge, metacognition and interpersonal factors are consistently found to be critically important to learning. Among the major reviews of how people learn, the one by Hattie is arguably the most neatly quantified. Hattie used a meta-meta-analysis of more than 800 meta-studies on student achievement. The analysis sought to identify the most important influences on student achievement. The meta-meta-study involved more than 50,000 individual studies in education, embracing more than 200 million students. Hattie deduced overall effect sizes for a wide range of influences/interventions and tabulated the results by quantifying effect size of individual factors (where effect size is defined as the difference between the pre and post intervention mean scores divided by the standard deviation).

Not all the influences/interventions listed in Hattie's table of effect sizes are relevant to university education. Piagetian programs, for example, are designed for young children, not university students (Jordan & Brownlee, 1981). Additionally, not all influences in his table are under the control of a teacher. Pre-term birth weight, for example, is correlated strongly with student achievement, but it cannot be influenced by a teacher (Hattie, 2009). Because this paper is concerned with what university teachers can do to affect educational outcomes, all influences/interventions that are substantially irrelevant to university students are excluded from consideration, as are influences that Hattie classifies as "Student Influences". Subject to the above restrictions, the top eight influences on achievement, according to Hattie's meta-meta-study, are shown in Table 1.

The following section describes how the influences listed in Table 1 were incorporated into the new course.

Design and implementation details

Spaced practice vs. mass practice

Skills practice is much more effective if it occurs over spaced intervals, rather than in a single block (Pashler et al, 2006). For this reason the common student practice of “cramming” for exams produces relatively poor long-term learning (Whitten & Bjork, 1977).

ENGG1300 has been structured to foster regular (spaced) practice over the entire 13 week semester. Accordingly, at the start of each week (typically Monday) a one hour lecture is provided, with this lecture providing a general introduction to the basic theory covered in the active learning sessions for that week. These lectures often include some “big picture” examples of a how this theory is applied in engineering practice (e.g. guest lectures from electrical engineers in the power industry to explain the power network). Students are then given the opportunity to participate in two 2-hour active learning practice sessions. The first session is scheduled in the first half of the week (Monday, Tuesday or Wednesday) and the second session is scheduled in the second half of the week (Thursday or Friday). The sessions involve both theoretical and practical tasks, and the tasks make explicit linkages between the theory and practice. There is a student-tutor ratio of about 20:1 in each of these sessions. Students are divided into class groups of 60-100 within an overall cohort size of approximately 270 students (2012, Semester 2).

Students are required to prepare for the active learning sessions by working through preparatory documents and/or videos. The active learning sessions were modelled on the “SCALE-UP” program at North Carolina State University (<http://www.ncsu.edu/per/scaleup.html>) and take place in a “SCALE-UP” style round-table collaborative classroom (with the additional inclusion of electronics laboratory equipment).

In the predecessor course (ELEC1000) there was a traditional structure with a weekly 2 hour lecture, a 1 hour weekly tutorial and a 2 hour laboratory session. In the tutorials there was a student-tutor ratio of about 40:1.

Table 1: Key influences on student achievement (Hattie, Visible Learning. 2009).

	Influence	Effect size
1.	Formative evaluation	0.90
2.	Microteaching	0.88
3.	Acceleration	0.88
4.	Teacher clarity	0.75
5.	Comprehension fostering via cognitive strategy scaffolding	0.74
6.	Feedback	0.73
7.	Teacher-student relationships	0.72
8.	Spaced practice vs. mass practice	0.71

Teacher-student relationships

Teacher-student relationships are very important in learning, and relationships which involve personalised attention are particularly effective (Bloom, 1984). In ENGG1300 students have a large amount of contact with staff so that relationships have time to develop. There are four hours of teacher-student contact per week during the active learning sessions and one hour during the lecture. The active learning sessions, in particular, are well suited to fostering good relationships because the staff-student ratios are usually quite small. Students can typically have personalised interaction with an individual staff member within seconds of requesting it.

Not all teaching is done by staff. Students are required to work in groups of three on the assigned tasks, and they must share measuring instruments and a computer. Much of the teaching is therefore effectively done by peers. Conveniently, then, the active learning sessions allow substantial time for peer based teacher-student relationships to develop.

Feedback

ENGG1300 has been designed to provide copious amounts of feedback from both peer and staff teachers. To facilitate feedback from peers, students are required to complete the active learning tasks in groups of three, with the membership of these groups being assigned by the unit co-ordinator. As students work through the tasks they typically discuss proposed solutions and ask one another questions. Students are also required to progressively write up their solutions to the set tasks on publicly viewable whiteboards. Since students can see what their peers are writing on the whiteboards, they are able to obtain inter-group feedback without even initiating verbal communication. The groups are re-assigned about every four weeks, so that students have the opportunity to obtain intra- and inter-group feedback from a number of different peers.

To facilitate feedback from staff, multiple tutors are assigned to the active learning sessions, and these staff members assist students as necessary. Since there are multiple tutors in the room, students have access to different types and styles of feedback. Feedback is also provided to students via a FAQ document which has been compiled by staff. Sample solutions for the theoretical exercises are also available after all sessions for the week were completed.

Comprehension fostering via cognitive strategy scaffolding

Studies have indicated that comprehension and learning can be improved by explicitly assisting students to modify and improve their cognitive strategies (Palincsar & Brown, 1984, Rosenshine & Meisler, 1992). While cognitive strategy development via appropriate scaffolding techniques is quite powerful, it can be challenging to implement because of motivational issues. This is so because changing one's thinking processes requires effort, and many students are inclined to resist such effort.

Because of the motivational challenges involved, the context for the cognitive strategy development is quite important. Motivation can be increased by embedding the cognitive strategy scaffolding into contexts which students see as relevant and/or timely. The cognitive strategy scaffolding therefore tends to be most effective if i) it is relevant to the tasks currently being completed by the students, or ii) it involves relevant contextualisation (Bransford et al, 2000). These can be provided, say, by inspiring engineering breakthroughs.

The appendix provides a sample case study which explores the cognitive strategies used to make a key engineering breakthrough. This case study (and others like it) can be used to trigger reflections, discussions and practice at improving cognitive strategies.

Teacher clarity

A number of strategies are used to ensure teacher clarity. Firstly, worked examples are routinely provided in both the lectures and the pre-reading material. This strategy is important because worked examples have been found to be highly effective in conveying concepts and expectations clearly (Hattie, 2009; Sweller et al, 1998). Secondly, active learning materials and pre-reading resources are regularly updated to improve clarity based on student and staff feedback. The staff and student feedback tends to occur quite naturally during the active learning sessions, because if there any ambiguities which impede student progress, these tend to come quickly to the attention of staff.

Regular tutor meetings are also held to monitor clarity and to facilitate the resource updating process. Additionally, there is a unit discussion forum where students can provide their own clarifications for one another.

Acceleration

Research in the neurosciences has shown that the brain functions best under the simultaneous conditions of high challenge and low stress (Reardon, 1999). Challenge is therefore extremely important in learning and students tend to achieve strongly in their learning if they are challenged to perform new tasks as soon as they are ready (rather than having to wait until all their peers are ready to progress) (Hattie, 2009). The active learning sessions are somewhat open-ended. Key concepts are covered early in the session, with additional activities being provided for the faster moving groups later in the session. Not all students are expected to finish all activities. Within any given active learning session, a group of three students is able to progress through the list of tasks as soon as they are ready.

Microteaching

Student achievement is strongly impacted if teachers monitor, reflect on, and gain feedback on their teaching (Hattie, 2009). In the “microteaching” technique teachers make videotapes of their teaching and then subsequently watch the videotapes in the presence of peers to monitor their teaching, to prompt reflection and to gain self and peer feedback (Perlberg, 1972). In ENGG1300 many of the pre-reading resources are provided on video. These videos are usually watched by the teacher as well as other staff members, and much monitoring, reflection and feedback tends to occur throughout this process.

Formative evaluation

A significant formative evaluation component is injected into ENGG1300 by the use of practice quizzes. Students are required to complete one assessable on-line quiz each week. Students also have the opportunity complete a non-assessable practice quiz in order to provide opportunities to enhance their skills in preparation for the assessable quiz. The latter enables them to have as many attempts at the questions as they wish, en route to obtaining the correct answer. The assessable quiz, by contrast, allows students three different quiz attempts.

Evaluation

Three different aspects of course evaluation will be considered in this section, namely (i) achievement, (ii) student satisfaction and (iii) impact on selection of Engineering discipline in second year.

(i) Achievement

The innovation in the course revolves largely around the active learning sessions. These sessions are entirely voluntary, since no assessment takes place in them except for a practical exam in Week 10. Students could therefore choose to absent themselves from the active learning sessions and study for the unit in more traditional ways if they wished.

Attendance at active learning sessions was surveyed around Week 11 of Semester 2, 2012 across the four active learning session groups (P1, P2, P3 and P4). Attendance varied across the different groups. One of the groups, P4, was anomalous in that it was much smaller than the other groups, and for this reason was excluded from consideration in the comparative analysis. One of the three large groups, P2 had a relatively high level of participation (around 74%), while the other two (P1 and P3) had a lower level of participation (around 36%). Because group P2 had a cohort which engaged quite strongly with the new learning initiatives within the course it was thus designated as the test group. The other large

groups, P1 and P3, had cohorts which engaged less with the new initiatives and more in a traditional way with their learning. The aggregate of these two groups were designated as the control group.

In performing the comparative analysis it was necessary to account for any potential differences in natural ability and motivational levels between the test and control groups. Rather than simply comparing the grades obtained by students in both groups, therefore, a different measure was compared. The quantity compared was the IGRGPA (improvement in grade relative to grade point average). The IGRGPA was the grade obtained in ENGG1300 minus the grade point average (GPA) of the student over all their university subjects. The IGRGPA, was thus effectively a measure of how far above their GPA the student performed.

It was found that the test group performed well above expectations based on their GPA (with an average IGRGPA of 0.631), while the control group only performed moderately above expectations (with an average IGRGPA of 0.286). A single tailed student t-test was performed to test the hypothesis that "The test group had a higher average IGRGPA score than the control group". The hypothesis was found to be true with greater than 95% confidence. The outcome of the statistical testing is summarised in Table 2.

Table 2. Comparison of performance of test and control groups in ENGG1300

	Mean IGRGPA	STD of IGRGPA	No of students	p-value
Control group	0.286	1.24	63	0.048
Test group	0.631	1.48	122	0.048

(ii) Student satisfaction

All first year engineering units were required to run student evaluations in Semester 2, 2012. During this semester ENGG1300 had approximately 270 students. The average unit satisfaction score for ENGG1300 was 4.4/5.0, while the average overall unit satisfaction score across the other three major Engineering units was 3.8/5.0 (with a range of 2.8 to 4.3). The score for ENGG1300 was thus higher than all other first-year Engineering courses and substantially higher than the average. Results were similar in Semester 1, 2013, when ENGG1300 had approximately 570 students – see Table 3.

Table 3. Overall unit satisfaction scores for simultaneously running first year units

Unit	Unit satisfaction scores, Sem. 2, 2012	Unit satisfaction scores, Sem. 1, 2013
ENGG1300	4.4/5.0 (273 students)	4.4/5.0 (493 students)
OTHER 1st YEAR ENGINEERING UNITS	Average of 3.8/5.0 - ranged from 2.8 to 4.3 (average of 572 students in each unit)	Average of 3.9/5.0 - ranged from 3.8 to 4.1 (average of 699 students in each unit)

(iii) Impact on student selection trends for second year engineering

In the year after the first running of ENGG1300 the number of students selecting Electrical Engineering (or a related dual major) as their core second year Engineering discipline rose by 37% (despite the overall second year student numbers rising by only 7%). It is conceded that there is no certainty that this increase in popularity of Electrical Engineering among second year students was due wholly (or even partly) to a positive experience in first year Electrical Engineering. Nonetheless, the increase did coincide with the introduction of the new course and is therefore noteworthy.

(iv) Implications and limitations of the study

Research has shown that the 8 influences in Table 1 all foster learning strongly. This study has shown positive results when these influences are all incorporated simultaneously in an Engineering course, but there were limitations to the study. Alternative explanations for the heightened outcomes of ENGG1300 include the increased effort on the part of the staff implementing the course and the relatively low student to tutor ratio for ENGG1300. For this reason, further research needs to be done to validate the approach in Engineering generally. For this validation to occur, the approach needs to be studied in other universities with other staff and in other year levels.

Conclusion

A new first year Electrical Engineering course has been designed and implemented in accordance with the evidence (from a meta-meta-study) on what fosters student achievement best. The new course has been found to score well above average in student satisfaction ratings and it has coincided with a notable increase in the popularity of Electrical Engineering among second year students. It also appears that the key innovative elements of the new course impacted on student performance in a substantial way. The positive outcome from this course augurs well for the future design and implementation based on evidence from meta-meta-studies.

Appendix

An engineering breakthrough and the cognitive strategies underpinning it (based on an article from IEEE Spectrum Magazine (Shapiro, 2010))

When Leonardo da Vinci looked at birds flying he saw that the birds flew not only by flapping their wings and creating new air currents, but also by exploiting air currents that already existed. He saw that birds would stretch out their wings over warm air pockets and rise almost effortlessly as the warm air rose. He then deduced a key *underlying principle*:

“Highly efficient motion can be produced by riding currents induced by thermal gradients”.

Da Vinci realised that he could apply the above principle to a new situation, namely to designing hang gliders with large “wings” which could carry human beings on thermal air currents.

Recently, engineers have used the same underlying principle identified by da Vinci to develop thermal underwater gliders. These gliders use the thermal gradients in the ocean to enable gliding through the water. The gliders are filled with an ice-like substance which expands when it freezes and contracts when it melts. The melting temperature, however, is higher than that of ice. When the glider is near the surface of the ocean the sun’s rays cause the ice-like substance to melt, thereby causing the glider to sink. As the glider sinks it cools because it receives less of the sun’s rays. When it sinks far enough, the ice-like substance solidifies, causing the glider to start rising. The process of rising and sinking continues indefinitely due to the thermal gradients which are always present in the ocean. If one puts a rudder on the glider, one can prompt the glider to not only move up and down, but also to move sideways as well (with an overall zig-zagging motion).

Because these gliders rise and sink effortlessly based on thermal gradients, they are extraordinarily efficient - about 1,000 times as energy efficient as motor cars. One of these gliders recently even completed a trip from the United States to Spain powered by just a simple battery!

Leonardo da Vinci and the thermal glider team both made their breakthroughs *by noting a key underlying principle and then applying that principle to a new situation*. This is a cognitive strategy used by almost all great engineers and scientists – they regularly try to extract important underlying principles from the situations they observe, and then make breakthroughs by applying those principles to new scenarios.

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