Vector Calculus for Engineers – The Academic Development Model

The final version of this paper was published in Community for Undergraduate Learning in the Mathematical Sciences (CULMS) 2013, issue 7, pp. 21-25. Any citations should refer to that version.

Vector Calculus for Engineers – The Academic Development Model

Tracy S. Craig and Anita Campbell
Academic Support Programme for Engineering in Cape Town (ASPECT)
Centre for Research in Engineering Education (CREE)
Tracy.Craig@uct.ac.za, Anita.Campbell@uct.ac.za

Abstract

We describe a model for a second year engineering vector calculus course designed to improve the support for students in an academic support programme where the historical pass rate for these students is typically below 50%. The model adopts some features of the support given to these students across multiple subjects in their first year. Academic development is described in the South African context. We describe the support experienced by our students in their first year, the contrast with the standard second-year experience and how our model aims to smooth the transition. Early indicators suggest the model is effective.

Introduction

The current and expected demand for engineers in South Africa has put pressure on universities to increase the number of engineering graduates. The University of Cape Town has chosen to achieve this goal not simply by accepting more students into their degree programmes but by improving teaching and learning so that a greater proportion of students graduate. A problematic, compulsory second-year course is Vector Calculus for Engineers, with an average pass rate over the past three years of only 62%. However, students in this course from a reduced-pace academic support programme have pass rates typically 20% lower. The relatively lower pass rate of this particular cohort of students motivated the model described in this paper, which is aimed at the academic development students.

To give some background to the development of the model, we first describe the existing academic support structures in the Faculty of Engineering and the Built Environment at the University of Cape Town and then more specifically in the Academic Support Programme for Engineering in Cape Town (ASPECT). We then describe the traditional vector calculus course and the proposed academic development model of the same course. We conclude by making some early comparisons between students' performances in the traditional course and the academic development course.

The Academic Development Context

The University of Cape Town, South Africa, offers so-called academic development programmes in all faculties except Law. The principle aim of the programmes is to offer access to tertiary studies to students from a previously disadvantaged educational background and thereby play a role in national and institutional transformation. South Africa's apartheid history left generations of coloured, African and Indian students without access to adequate education. While the country tries to reform the school system, thousands of potential university students would be denied access to tertiary institutions unless efforts are made to offer redress (Scott, Yeld & Hendry, 2007).

In the Faculty of Engineering and the Built Environment (EBE) the academic development programme (ASPECT) offers an extended curriculum programme. The students who are accepted to ASPECT narrowly missed the points requirement for entry into mainstream engineering, however they have excellent mathematics and science results and their educational records suggest they might be able to succeed at university. For many of these students, immediate placement into mainstream studies would not be advisable as they struggle with the simultaneous challenges of language, work load, cognitive demand as well as having to deal with cultural and social dislocation (Kapp et al, forthcoming; Craig, 2011). In the ASPECT model, students are allowed to complete their first two years' of study over three academic years. The subjects completed are identical to those in mainstream studies apart from a small entry-level support course in communication – there are no bridging courses – the load is simply somewhat lighter (Pearce, Campbell, Craig, le Roux, Nathoo and Vicatos, 2012).

Until 2013, ASPECT academic support was only offered in first-year, thereafter the students joined much larger mainstream classes. In 2013 we are investigating the worth of extending academic support to the first semester of second-year mathematics, in an effort to alleviate the shock of the transition from first to second year (Pearce et al, 2012). In their first year, the students receive extensive support which is traditionally not extended to any of their second-year courses.

ASPECT First-year Mathematics Support

First-year ASPECT students enrol for three and a quarter courses: mathematics, either physics or chemistry, an introductory engineering course and a quarter course on communication. This is in contrast to their mainstream colleagues who mostly enrol for six courses in their first year, for instance mathematics, physics, chemistry, engineering drawing, statics and an introductory engineering course. (This stated curriculum does differ across engineering departments). ASPECT lecturers teach the mathematics, physics and communication. In mathematics, the syllabus is identical to the mainstream course, however the assessment differs to allow for different timing, a larger number of smaller assessments, and a variety of assessment tasks. The differences between ASPECT and mainstream are

- Double period lectures (105 minutes) instead of single periods (45 minutes)
- More lecture times per week
- 3 hour tutorials instead of 2 hours (in mathematics)
- Greater number of hours of lecturer availability
- Additional resources
- Regular and varied assessment tasks with fast feedback
- A small class (60-90 students) instead of mainstream's 450-500 students split across three venues and three lecturers.

The final version of this paper was published in Community for Undergraduate Learning in the Mathematical Sciences (CULMS) 2013, issue 7, pp. 21-25. Any citations should refer to that version.

The students in general do well in first-year ASPECT mathematics. The pass rates are high (typically between 75% - 90%), as are student approval ratings. We strive to maintain a sense of community, with a community outing once a year, a group photo, an indispensable mother-figure secretary and continual positive reinforcement from all the staff.

Vector Calculus

It is from this supportive atmosphere that the ASPECT students would enter second-year mathematics with the mainstream students. The first semester covers vector calculus, a course which is notoriously challenging. The students enter the course already intimidated by its reputation, the number of classroom contact hours decreases from 11 to 6, the lecturers teach multiple courses and unavoidably have limited consultation time, the resources are limited, the classes are large, the assessment tasks are few, lengthy and difficult. The pass rates for vector calculus are low for the entire cohort but even lower for the ASPECT students (see Table 1).

Table 1. Pass rates in vector calculus

	Pass rate in %	
	Entire cohort (*N*)	ASPECT (*N*)
2010 semester 1	67.7 (589)	41.4 (99)
2010 semester 2	54.9 (226)	42.9 (56)
2011 semester 1	73.1 (465)	53.4 (58)
2011 semester 2	44 (302)	38.7 (62)
2012 semester 1	71 (594)	51.6 (126)
2012 semester 2	60.9 (233)	46.9 (96)

The issue of raising the pass rate in vector calculus overall is a topic of much animated discussion in the halls of our institution, but the issue of how to raise the pass rate of ASPECT students is what concerns us here. The course is challenging for any student. The shift from single variable to multivariate calculus is more than simply a matter of the symbolic demand of calculus with more variables. Worsley, Bulmer and O'Brien (2008, p. 143) suggest that multiple integration can be seen as a 'threshold concept' (Meyer and Land, 2006) with specific areas of difficulty identified as the changing between coordinate systems, working out limits of integration and changing the order of integration. Hesterman, Male and Baillie (2011, p. 622) describe troublesome topics in vector calculus as *conceptually difficult*, for example understanding the distinction between vectors and scalars and between velocity and acceleration, and *alien*, for example using the axis of rotation to represent angular motion, understanding the physical interpretation of dot and cross products, understanding that a vector with constant magnitude can have a non-zero derivative, and using different notations for vectors interchangeably. In our experience, the demands of 3-dimensional visualisation and the many conceptual challenges around continuity and differentiability in these contexts challenge all students.

Do ASPECT students, with their often weaker school grounding, find greater trouble with these visual and conceptual contexts? Or is it more a case of having had the rug pulled out from under them with the shift from extensive academic support to very little? In 2013 we are implementing and investigating whether continuing ASPECT involvement into the first semester of second year might increase the success of ASPECT students in the course.

The Vector Calculus Academic Development Model

It is neither possible not advisable to mimic the first-year support in second year. The students' timetables do not allow for double periods, nor for much increase of the number of lectures. In addition, the students need to adjust to the demands of mainstream tertiary study, the provisions made in their first-year having been always planned to be decreased in their second year when they found their feet. The idea is to make the shift from first-year to second-year mathematics less like a step function and more like a steep curve.

The ASPECT vector calculus timetable has more classroom contact hours than mainstream vector calculus: 5 single lecture periods per week instead of 4, and 3 hours of afternoon workshop instead of 2. In addition, we have small tutorials dotted throughout the week for students to complete assignments or to ask general work-related questions. Because the ASPECT lecturer is dedicated to this course alone, rather than the two or three courses usually taught (and prepared for, and marked, and so on) by the three mainstream lecturers, more "open door" time is possible for students to ask for help. The class is small (85 students) in contrast to mainstream's 470 students (divided in to three classes of approximately equal size). A small amount of time is available during class time for the students to work interactively, rather than more passively observe the lecturer. Beyond that, the courses are identical. All lecturers work from the same notes, to the same timetable. The weekly tutorial assignments and homework are the same and the assessment tasks are the same.

Discussion and Conclusions

What causes the ASPECT students to fare so much worse than their so-called mainstream counterparts? ASPECT students, on the whole, have weaker university entry level results than mainstream students, but not in mathematics and science. The school-leaving mathematics and science results of ASPECT students are comparable with those of the majority of mainstream students. The ASPECT model is predicated on the understanding that students with school-leaving results necessary for success in engineering studies, but coming from backgrounds with historically weak support for the demands of an English language institute of higher education, will achieve success if supported through initial cultural, language and academic literacy difficulties. Some students fail to thrive in the ASPECT environment, but the majority do well. Is the poor performance in vector calculus due to these students lacking the mathematical skill to deal with the course? We in ASPECT consider this not to be the case. These students are academically competent - as competent as the majority of the mainstream cohort.

If the students are sufficiently mathematically competent, then perhaps their impediment to success is greater than that of the mainstream students due to the sudden change in academic support, a change with which the mainstream students do not have to contend (at least in the first- to second-year transition). It is this abrupt change which we seek to ameliorate with the ASPECT vector calculus offering. So far, the signs are good. One class test has been written. The overall pass rates are disappointing, but what is notable is that the pass rate of the ASPECT vector calculus cohort is identical to that of the mainstream cohort: 55% in both cases.

The students who are repeating the course (and hence have experienced the mainstream system) report favourably on the ASPECT vector calculus system. The weekly tutorial assignments, meant to be completed in the 2-hour tutorials (3 hours in ASPECT) continue to be worked on constructively in the extra (short) tutorial periods throughout the week, making it clear that the extra class time is advantageous. We shall continue to monitor both the class's absolute progress and their results relative to the mainstream cohort, but evidence to date suggests that the academic development offering of second-year vector calculus is effective. Should the model raise the performance of academic development students to that of the mainstream students, this pilot vector calculus course will continue to be run for future ASPECT classes. Further improvement may involve finding ways to improve absolute performance of the entire cohort as well as relative performance between groups.

References

Craig, T. S. (2011). Student identity and the need to make classroom mathematics relevant to engineering practice, in *Proceedings of the Conference of the Society for Engineering Education of South Africa*, Stellenbosch, South Africa.

Kapp, R., Badenhorst, E., Bangeni, B., Craig, T. S., Janse van Rensburg, V., le Roux, K., Prince, R., Pym, J., & van Pletzen, E. (forthcoming). ‘Out of order’: Successful students’ negotiation of working-class schooling in post-Apartheid South Africa. Accepted by *Perspectives in Education* for 2014 publication.

Hesterman, D. C., Male, S. A. & Baillie, C. A. (2011). Some potential underlying threshold concepts in engineering dynamics. In Y. M. Al-Abdeli and E. Lindsay (Eds.), *Proceedings of the 2011 AAEE Conference*, Fremantle, Western Australia. Barton ACT, Australia: Engineers Australia.

Meyer, J. H. F. & Land, R. (2006). *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge*. New York: Routledge.

Pearce, H., Campbell, A., Craig, T. S., le Roux, P., Nathoo, K. & Vicatos, E. (2012). The articulation between the extended (5-year) and mainstream (4-year) programmes in Engineering at the University of Cape Town: Reflections and Possibilities. Paper presented at the HELTASA Foundations Programmes Colloquial in Pretoria, June 2012.

The final version of this paper was published in Community for Undergraduate Learning in the Mathematical Sciences (CULMS) 2013, issue 7, pp. 21-25. Any citations should refer to that version.

Scott, I., Yeld, N. & Hendry, J. (2007). A case for improving teaching and learning in South African higher education. Higher Education Monitor No. 6. Pretoria: Council on Higher Education. Available at http://www.che.ac.za/documents/d000155/index.php.

Worsley, S., Bulmer, M. & O'Brien, M. (2008). Threshold concepts and troublesome knowledge in a second-level mathematics course. In A. Hugman & K. Placing (Eds.), *Symposium Proceedings: Visualisation and Concept Development*, (pp. 139–144). UniServe Science, The University of Sydney . Available at http://openjournals.library.usyd.edu.au/index.php/IISME/article/view/6256/6904