Mind the gap: Science and engineering education at the secondary–tertiary interface

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In the South African higher education sector, there is increasing concern about the poor retention and throughput rates of undergraduate students. There is also concern that the participation rates in higher education, relative to population demographics, remain extremely racially skewed. With the quality of schooling unlikely to change dramatically in the short term, universities need to look for ways to improve student success, particularly in science and engineering, where graduates are needed for a range of key roles in society. Here we review the research presented at a forum held by the Academy of Science of South Africa in 2010, which sought to bring together the latest expert thinking in this area. The major focus of academic development to date has been the establishment of extended degree programmes. However, it is clear that this model has limited capacity to deal with what is, in fact, a much broader problem. We summarise existing interventions aimed at reducing the 'gap' between secondary and tertiary education, and describe key innovations in mainstream programmes that are possible at the levels of pedagogy, curriculum and institutional environment, some of which are also becoming established internationally in science and engineering. Driving such initiatives will demand visionary university leadership in order to effect the integrated and holistic change that is needed.

Introduction

Although the South African higher education sector overall has expanded significantly since 1994, the participation rates in higher education relative to the population remain extremely racially skewed. In 2009, the participation rate, that is, the total headcount enrolment as a percentage of the total population between the ages of 20–24, was only 13% for Black students compared with 57% for White students.[1] In addition, there is increasing concern about the poor retention and throughput rates of undergraduate students. A recent Council on Higher Education (CHE) study[2] in which the 2000 student intake to higher education was analysed provided compelling evidence that across the sector there is a high attrition rate at first year, a low overall completion rate and a very small group who complete in regulation time. Within the science, technology, engineering and mathematics (STEM) fields, specifically, only 21% of students in life and physical sciences completed a degree in 3 years, and in engineering only 32% of students completed the degree in the regulation time of 4 years. Clearly the current structures and processes are not effective for the majority of students, who, given the low participation rates in higher education (17% of the age cohort in 2009), are, in fact, the 'cream of the crop' of school-leavers.

In relation to the underperformance of undergraduate students, the level of preparation of first-year students for university studies has long been a concern, with the interface between school and higher education often characterised in terms of a discontinuity or 'articulation gap'.[3] Over the last few decades, the predominant mode for responding to this gap has been the establishment by the higher education sector of what are currently termed 'foundation programmes' or 'extended curriculum programmes'.[4] The so-called 'mainstream' programmes have remained relatively unchanged over this period. A Forum hosted by the Academy of Science of South Africa (ASSAf) in October 2010 focused attention on existing interventions, together with opportunities and imperatives for further mainstream responsiveness. The ASSAf Forum invited evidence-based analyses and evaluation to provide informed perspectives to identify ways forward for STEM education in South African higher education institutions. The Forum furthermore offered a showcase of current best practice, with exemplars of lecturers who have introduced course and curriculum innovations that are 'minding the gap' in a responsive manner. A key starting point for the Forum was the recognition that weaknesses and inequities in the schooling system are not likely to be solved in the short term. Higher education institutions must therefore share responsibility with other education sectors in overcoming the legacy of apartheid and building a better future for South Africa and its citizens.

We summarise the key findings from the scholarly work presented at the ASSAf Forum, as well as draw on other relevant science and engineering education research at the secondary–tertiary interface. We attempt to synthesise, in areas where there is currently sufficient evidence, a tentative consensus position (what do we know?) and highlight areas for future research and innovation (what do we still need to know?).

International context

As a starting point, it is important to locate concerns about the South African articulation gap within the international context of higher education. Although there are particular local features that can be traced to the impact of apartheid, the broader issues have strong international resonance. Higher education, traditionally catering to an elite group, has expanded dramatically in the second half of the 20th century around the world, and most countries now aspire to having the majority of their young people complete post-secondary education.[5-7] At the same time, in many contexts the system has been arguably slow to respond to the implications of such massification, but in recent times there has been an increased focus on issues around teaching and learning in higher education.[8,9]

The debate around the 'gap' between schooling and higher education is not unique to South Africa. Here it needs also to be acknowledged that schooling is not only geared towards higher education preparation, but has an important, far broader, role in society in producing well-rounded individuals who can take up their places in a democracy and in the world of work.[10]

The gap in South Africa – yesterday and today

Concern about the 'gap' between students' capabilities and university's expectations is not new in South Africa. Akoojee & Nkomo[11] highlight several previous studies that foregrounded students' levels of underpreparedness for higher education. For example, a study commissioned by the Joint Matriculation Board in 1963 found that only 55% of the first-year students – at that time mostly White students – who had entered university had ultimately graduated.[12] The reasons given for failure were poor school preparation and the 'weaknesses' of university teaching and learning. An even earlier study, commissioned by the Minister of Education in 1936, found high first-year failure rates and attributed these to 'a mix of the transition from school to university and the inadequacy of the university teaching system'[13(p. 387)].

While concern about the articulation between school and higher education is not new, the introduction of new school curricula and school-leaving examinations in mathematics and physical science has precipitated renewed concerns about students' levels of preparedness, and concerns about their poor performance in first-year university exams. The new curricula were first implemented in the General Education and Training band in the late 1990s and at the Grade 10 level in 2006, and the new school-leaving qualification, the National Senior Certificate (NSC), was first offered in 2008.

A sharp decline in first-year mathematics and science performance in the latter part of the 2000s has been reported in several studies. Hunt et al.[14] examined students' school-leaving scores and first-year performance at the University of the Witwatersrand over the period 2006–2010. They found that, with the introduction of the NSC in 2008, enrolment numbers increased but pass rates decreased in quantitative courses such as mathematics, physics, chemistry and economics. They suggested that inflated NSC mathematics scores underlie these lower pass rates, with inflation of around 20–25 percentage points compared to the former higher-grade mathematics scores. Dennis & Murray[15] similarly noted that grade inflation in the NSC mathematics appeared to underlie some of the poor performance in first-year mathematics at the University of the Free State. These findings agree with the analysis of the mathematics examination in 2008 by Umalusi[16] which showed that the cognitive demand was similar to the former standard grade paper, thus causing a substantial increase in the marks obtained by learners who would have written the higher-grade paper previously. However, Collier-Reed et al.[17], who analysed first-year mathematics performance for engineering students at the University of Cape Town over the period 2005–2010, noted a gradual deterioration in the preparedness of the incoming first-year students during this period, rather than a dramatic downward shift with the introduction of the NSC qualification in 2008.

In addition to broad statistical analyses of student performance, in-depth research has also detailed subject-specific performances. Several investigations into first-year students' abilities in mathematics have been undertaken. Dennis & Murray[15], in an analysis of a mathematics comprehension test, showed that students perform well at basic mathematics but poorly in analysis and synthesis. Engelbrecht et al.[18] noted a decrease in 'factual knowledge' in particular topics such as logarithms, exponents and parts of trigonometry; they also noted a decline in algebraic manipulation skills, in graphical interpretation and in precision of mathematical formulation. On the other hand, they found that these students showed increased personal confidence and a 'willingness to try'.

In the area of chemistry, Potgieter and Davidowitz[19] conducted a longitudinal study tracking first-year students' conceptual understanding since 2005, showing that in a number of topic areas, students' knowledge was not at the level traditionally expected by first-year lecturers. The results were fairly stable between 2005 and 2007 but showed a sharp decline in 2009 in all topic areas, most significantly in acids and bases (not currently tested in the final examination) but also notably in atoms and ions, mole concept, reactions, and general quantitative and literacy skills.

In summary, a decline in success in first-year mathematics and science courses has been observed at a number of institutions in the latter part of the 2000s, with some data suggesting that this decline is not solely attributable to the introduction of the NSC qualification in 2008. In a number of key subject areas, researchers have started to document specific conceptual difficulties experienced by students. Thus, the current status of the 'gap' between schooling and higher education in South Africa is being characterised in both broad and detailed aspects.

Efforts to address the gap

Selection and placement

With regard to improving selection measures, a number of studies have explored the predictive value of various measures, including matriculation scores and other access tests.[20-22] One set of tests that has become nationally available is the National Benchmark Tests (NBTs), developed under the auspices of Higher Education South Africa.[23] The view is developing nationally that students should be placed into programmes that maximise their potential to succeed in their studies. Given that only a small minority of prospective students obtain NBT results which indicate that they are sufficiently prepared for mainstream university study, placement in extended curriculum structures may, in fact, be appropriate for a larger proportion of the current and future student intake.

However, it was deliberated and concluded at the Forum that a focus solely on the predictive value of various selection measures is insufficient for responding to the gap, unless such a focus is coupled with changes in the educational experiences provided to undergraduate students.

Foundation provision and extended degree programmes

Foundation and extended programmes were offered at some South African universities beginning in the late 1980s, many of which were initiated with donor funding.[4] However, in 2006, the government introduced earmarked funding for foundation provision, which made it possible for most universities to offer extended curricula, particularly in science and engineering. It is required that all foundation courses should be credit-bearing and form part of formal extended degree programmes. As Ellery[24] noted, the significance of many of these programmes has been as 'sites for curriculum innovation and research that can engage with some of the pedagogical issues at stake' (p. 1078). Forum presentations and other studies have highlighted ways in which foundation programmes have been sites of innovative curriculum and pedagogical practices, for example problem-oriented learning, fostering student activity and engagement, developing students' identities in becoming scientists and engineers and explicitly focusing on developing students' academic literacy in disciplinary contexts.[25-28]

Nonetheless, the institutional location of these foundation and extended programmes – often separate from mainstream science and engineering departments – is considered a crucial limitation. Scott[29] advocates rethinking the structure of entire undergraduate programmes, rather than having a foundation year 'grafted' onto inappropriate or unchanged mainstream curricula. The ASSAf Forum thus concluded that mainstream responsiveness is needed.

Towards mainstream responsiveness

Three areas were identified in which mainstream responsiveness is needed: pedagogy, curriculum and institutional culture. These three levels can be seen to parallel the following 'levels of responsiveness' identified in earlier work by Moll[30]: learning responsiveness, disciplinary responsiveness and institutional or cultural responsiveness. (Moll also identified a further level of economic and policy responsiveness as important for underpinning change.) Importantly, significant impacts will only be seen if response is integrated at all three levels.

Pedagogy

In the arena of pedagogy (i.e. teaching practice), three broad themes are discernible in the literature: active student engagement, development of conceptual understanding, and making explicit the academic literacy practices of the discipline. Drawing on best practice internationally in these three areas is important to improve student learning for all students, and not just for underprepared students. It was noted that top international institutions are not static in their teaching practice but are continually exploring new possibilities and modes for facilitating student learning. For example, recent teaching innovations in undergraduate science at MIT and Harvard are aimed towards facilitating better undergraduate learning.[31]

Many of the best teaching practices in mathematics and science undergraduate education involve a central focus on active student engagement in the class.[25-28,32] Helping students to become independent learners outside of class time is also important, with technology having the potential to support this kind of engagement. Educators at the Forum pointed to the power of peer collaboration, and the importance of creating integrated classroom communities, drawing on the resources inherent in the diversity of the South African class. In this regard, we are often guilty in South African science and engineering curricula of overscheduling students' time. Wolff[33] points to the importance of individual and peer work that takes place outside scheduled 'contact time' and how innovative timetabling can better support this.

Building on well-established literature, particularly in science education, many researchers[26,34] point to the importance of focusing on the development of conceptual understanding. Basson[35], working in a distance learning context, has shown how careful design of resource materials can support conceptual understanding, even without the presence of a teacher.

With regard to 'language' issues, a number of researchers draw on both international research and local evidence to suggest that academic literacy as part of disciplinary pedagogy may be more effective than stand-alone English language courses.[36] Jacobs[37] notes the common tendency in higher education to conflate academic literacies and 'English language proficiency'. She argues for a shift in focus from English proficiency towards changing pedagogy, with lecturers viewing themselves as academic literacies practitioners as well as disciplinary experts. From this perspective, it is the lecturer's role to make the disciplinary discourse explicit to students and to initiate them into the forms of inquiry and knowledge production modes of their discipline.[38] This process is sometimes referred to as widening 'epistemological access' to disciplines.[39]

In order to support disciplinary lecturers to take on this new role, Jacobs[40] presents a model of 'collaborative pedagogy'. Instead of teaching 'add-on' language courses, academic literacies practitioners work collaboratively with disciplinary lecturers to help them to make the literacy practices of their discipline explicit to students, for example, by making explicit the particular ways of reading, writing, using representations (graphs, symbols, etc.) and thinking that characterise science disciplines. Wolmarans and Shaw[41], Marshall and Case[42] and Winberg[32] provide examples of courses with an explicit focus on the literacy practices of engineering and physics, and on developing students' identities as engineers and scientists. Hurst[43] and Kirby[20] argue for teaching that does not assume that students have the academic literacy skills required for success in particular disciplines, but rather makes these explicit.

In summary, it has been argued that mainstream lecturers need to take a scholarly approach to teaching and learning. Innovative and progressive pedagogies need to be explored, focusing in particular on how to facilitate student learning, as opposed to the prevalent practice of presenting information. Specific strategies include using active engagement in class, developing students' conceptual understanding, and working with academic literacies experts to make the literacy skills for the discipline more explicit. It is clear that collaboration across subject areas within a particular programme can be an important resource in this work.

Curriculum

The importance of basing curriculum reform on scholarly approaches is noted in several studies. For example, Wolff[33] and Case[44] point to the importance of taking the structure of knowledge into account in curriculum reform, in the contexts of, respectively, a mechatronics curriculum and problem-based engineering curricula.

With regard to curriculum structure, there is ongoing debate nationally about whether to extend the length of the standard degree. On the one hand there is a view that universities need to work within the scope of the existing degree length, and on the other hand there is an argument that the standard BSc and BEng degrees need to be extended by a year. A recent CHE report lays out a possible framework for extended degree structures.[45] Whatever the outcome of this debate, we need to 'normalise the norm' – whatever is the standard period for the degree, we need to provide a curriculum framework such that the majority of students will graduate within this time. In South Africa, given that only about one-third of students complete undergraduate degrees in regulation time, most students effectively follow curricula that are not coherent. Importantly, higher degree offerings need to start where students are. There is no international norm on the level at which the first year is pitched, especially with differing modes and lengths of schooling in different parts of the world. South African higher education needs to develop curricula that articulate better with school-leavers' needs and capabilities. It is repeatedly emphasised in STEM education literature internationally that 'we need to teach the students we have, not the ones we wish we had'[46]. For example, Engelbrecht et al.[18] argue that the teaching pace at first-year level needs to decrease and that traditional, content-heavy first-year courses need to be revised. They also note that 'many first-year mathematics courses have shifted to a more theoretical approach for which the new intake of students is clearly not ready'[18(p. 12)]. In this regard, the University of Pretoria has recently altered its first-year mathematics course.[18]

While the focus on student preparedness is crucial, it is also important that curriculum reform is oriented towards desired graduate attributes, particularly taking into account what it is that society requires from science and engineering graduates in the context of 21st-century challenges.

In summary then, curriculum development will be a key aspect of mainstream responsiveness. As much as it is important to work carefully at the first-year level to articulate with where school-leavers are coming from, at the same time it is crucial to holistically rethink and update entire programme structures in a scholarly manner.

Institutional culture

Recognising the significance of broader campus life in supporting student learning,[47] there is clear evidence that responsiveness is needed at the highest level in order for changes in pedagogy and curriculum to be effective.

Presenting evidence that even 'top' students are bewildered and confused in their first year at university, researchers at the Forum called for more holistic interventions that support students' orientation to the expectations of university, given that these are increasingly different from those in the school environment.[48,49]

If academics are to put the requisite effort into reforming both pedagogy and curriculum, then the institution needs to support, require and reward this effort. There remains a debate on whether career paths in higher education which focus only on teaching are desirable or not. It has been suggested that each department needs to have at least a few academics with particular expertise in educational scholarship in that discipline.[50,51]

The ASSAf Forum noted that top level leadership is key to driving mainstream responsiveness in terms of pedagogy and curriculum. A useful exemplar of a holistic response of this sort was provided by Prof. Johan Engelbrecht, in his keynote address outlining the response of the Faculty of Natural and Agricultural Sciences at the University of Pretoria to this situation: high-impact modules are identified, support is put in place to change pedagogy and curriculum in these modules, and recognition is given for the time and effort that this work involves. An interesting international exemplar of mainstream responsiveness is the Science Education Initiative at the University of British Columbia, established by Physics Nobel Laureate Carl Wieman, which supports Science Faculty departments to adopt scholarly and research-based approaches to improving undergraduate science education.[52,53]

In terms of the physical environment of the university, changes in pedagogy will require spaces to support collaborative and interactive learning. Many undergraduate science courses worldwide are no longer taught in tiered lecture theatres but rather in flat-space, interactive studio-like venues (for example, the SCALE-UP project,[54] adopted in many US universities including MIT). Furthermore, it is important to recognise that the campus also needs to provide social learning spaces which support unscheduled peer collaboration.[33,55]

In summary, the role of institutional culture in supporting mainstream responsiveness is significant. Campus life needs to support students' orientation to university and overall well-being. Promotion and reward structures need to recognise the effort required for academics to transform pedagogy and curriculum. Finally, in line with international trends, examining the role of the physical spaces in the university in supporting teaching and learning will be a fruitful area for innovative work.

Areas for further research and innovation

This overview of the work presented at the ASSAf Forum, coupled with key literature on undergraduate science and mathematics education, points to important areas for future research and innovation. Firstly, the 'language issue' remains untheorised in many undergraduate programmes, with 'add-on' language courses still dominant. This situation may be a result of the issue being 'misrecognised'[56] as an English fluency issue rather than about induction into the disciplinary discourse and the literacy practices of particular disciplines.[36,40] Nonetheless, there is evidence that the problem, for at least some students, can be described as a basic language one with regard to fluency in the language of learning and teaching.[43]

Secondly, the focus in many studies is on the *deficits* of the current student intake. However, there is some research evidence that the shifts in the school curriculum have also produced particular strengths. For example, mathematics students were found to be better prepared than previous cohorts in relation to personal attributes such as confidence and willingness to try and did not merely 'blindly follow the method suggested by the lecturer'[18]. The challenge remains for higher education to harness these strengths. We also need more research on what students *are* gaining during their studies at university – the pre-post-test analysis in chemistry by Potgieter[34] suggests a useful methodology and important findings with regard to the significance of curricular and institutional arrangements.

Thirdly, a great deal of work is needed in investigating how innovative curricula and pedagogy developed for a minority of students in existing extended degree programmes can be expanded and integrated with the mainstream curriculum to better serve the needs of the majority.

Finally, there is some discussion on the new NBTs in the higher education sector – with these tests increasingly playing a role in selection and placement at some institutions there is an urgent need for broad and critical engagement with these new measures.

Conclusion

To date, the response of South African universities to the perceived gap between schooling and higher education has been largely confined to the arena of foundation and extended programmes. Here, drawing on key findings presented at the ASSAf Forum, as well as on other science and engineering education studies, we argue that a wider degree of mainstream response from the STEM higher education sector is required if South Africa is to meet equity and development needs in the STEM sector.

There is now substantial evidence that, despite the participation of only a small select portion of the age cohort in higher education, success rates in the STEM sector are low. It is not a small, identifiable group that are struggling while the majority of the class is succeeding; even at top institutions it is often the majority of the class who are not coping with the curriculum as it is designed. Thus it can be seen that tweaking selection processes is unlikely to deliver dramatic changes. Moreover, foundation and extended programmes alone cannot address this issue; rather, mainstream responsiveness will be key to addressing this situation.

An integrated and coordinated response is needed at levels of pedagogy, curriculum and institutional culture. These are complex challenges, not amenable to simple technical solutions, and a scholarly approach is required. International best practice provides an important reference point for this work.

These interventions will require leadership and vision to be exercised by university leaders, together with focused action plans that build strong collaborative teams of mainstream disciplinary lecturers. If we continue to fail to create the conditions whereby our highly selective intake of students can succeed in higher education, the future of science and engineering in this country will indeed be in peril.

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Authors' contributions

J.C. and D.M. initiated the paper following their convening of the ASSAf Forum. D.G., also a participant at the Forum, provided additional input. All authors served on the ASSAf STEM committee.

References

1. Council on Higher Education. Teaching and learning [homepage on the Internet]. c2009 [cited 2013 Jun 24]. Available from: http://www.che.ac.za/heinsa/tl/participants/
2. Scott I, Yeld N, Hendry J. A case for improving teaching and learning in South African higher education. Pretoria: Council on Higher Education (CHE) and Higher Education Quality Committee (HEQC); 2007.
3. Department of Education. White paper on higher education. Pretoria: Department of Education, Government of the Republic of South Africa; 1997.
4. Rollnick M. Identifying potential for equitable access to tertiary level science: Digging for gold. Dordrecht: Springer; 2010. http://dx.doi.org/10.1007/978-90-481-3224-9
5. Marginson S. Markets in education. Sydney: Allen & Unwin; 1997.
6. Barnett R. The limits of competence: Knowledge, higher education and society. Bristol: Open University Press/SRHE; 1994.
7. Altbach PG, Reisberg L, Rumbley LE. Trends in global higher education: Tracking an academic revolution. UNESCO 2009 World Conference on Higher Education; 2009 July 5–8; Paris, France. Paris: UNESCO; 2009. Available from: http://www.uis.unesco.org/Library/Documents/trends-global-higher-education-2009-world-conference-en.pdf.
8. Kreber C. Setting the context: The climate of university teaching and learning. New Directions for Higher Education. 2006;133:5–11. http://dx.doi.org/10.1002/he.200
9. Haggis T. Pedagogies for diversity: Retaining critical challenge amidst fears of 'dumbing down'. Stud High Educ. 2006;31(5):521–535. http://dx.doi.org/10.1080/03075070600922709
10. Aikenhead G, Orpwood G, Fensham P. Scientific literacy for a knowledge society. In: Linder C, Ostman L, Roberts D, Wickman P-O, Erickson G, MacKinnon A, editors. New York: Routledge; 2011. p. 28–44.
11. Akoojee S, Nkomo MO. Access and quality in South African higher education: The twin challenges of transformation. South African Journal of Higher Education. 2007;21(3):385–399.
12. Malherbe EG. Education in South Africa.; Volume 2. Cape Town: Juta and Company; 1977. p. 1923–1975. http://dx.doi.org/10.1111/j.1813-6982.1965.tb01902.x
13. Malherbe EG. Manpower training: Educational requirements for economic expansion. S Afr J Econ. 1965;33(1):29–51.
14. Hunt K, Ntuli M, Rankin N, Schöer V, Sebastiao C. Comparability of NSC mathematics scores and former SC mathematics scores: How consistent is the signal across time? Educ Chang. 2010;15(1):3–16. http://dx.doi.org/10.1080/16823206.2011.574097
15. Dennis CR, Murray DM. Success in first-year mathematics: School-leaving examinations and first-year performance. S Afr J Sci. 2012;108(7/8):5–7. http://dx.doi.org/10.4102/sajs.v108i7/8.1325
16. Umalusi. 2008 Maintaining standards report. Part 3: Exam paper analysis. Pretoria: Umalusi; 2009.

17. Collier-Reed BI, Wolmarans N, Smit R. The impact of NSC mathematics on student performance in mathematics in first-year engineering programmes: Where does the gap lie? ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

18. Engelbrecht J, Harding A, Phiri P. Are OBE trained students ready for university mathematics? Pythagoras. 2010;72:3–13.

19. Potgieter M, Davidowitz B. Grade 12 achievement rating scales in the new National Senior Certificate as indication of preparedness for tertiary chemistry. S Afr J Chem. 2010;63:75–82.

20. Kirby NF. Foundation science student performance explained: Insight gained at UKZN. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

21. McKenzie B, Kioko JI. Minding the gap: Identifying risk profiles of first-time entrants for the Diploma in Nature Conservation at the Cape Peninsula University of Technology. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

22. Jacobs M, De Bruin GP. A framework for the appropriate placement of first year students in Science, Engineering and Technology Programmes at a SA University. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

23. Yeld N. Critical questions? Some responses to issues raised in relation to the national benchmark tests project. South African Journal of Higher Education. 2007;21(5):610–616.

24. Ellery K. Knowing, acting and being: Epistemological and ontological access in a science extended studies course. South African Journal of Higher Education. 2011;25(6):1077–1090.

25. Grayson DJ. Design of the Engineering Augmented Degree Programme at the University of Pretoria. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

26. Loji K. Integrating thinking skills into subject content to improve engineering learners' problem solving abilities. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

27. Malan S, Marnewick M, Lourens E. From Eersterivier to a PhD: Bridging the gap. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

28. Volkwyn T, Herbert M, Maclons, Conana H, Marshall D. 'Becoming a physicist': The implementation of a research based physics course in an extended curriculum programme. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

29. Scott I. First-year experience as terrain of failure or platform for development? Critical choices for higher education. In: Leibowitz B, Van der Merwe A, Van Schalkwyk S, editors. Focus on first-year success. Stellenbosch: SUN Press; 2009. p. 28–30.

30. Moll I. Curriculum responsiveness: The anatomy of a concept. In: Griesel H, editor. Curriculum responsiveness: Case studies in higher education. Pretoria: South African Universities Vice-Chancellors Association; 2004.

31. Crouch CH, Mazur E. Peer instruction: Ten years of experience and results. Am J Phys. 2001;69(9):970–977. http://dx.doi.org/10.1119/1.1374249

32. Winberg C. Teaching engineering/engineering teaching: Interdisciplinary collaboration and the construction of academic identities. Teach High Educ. 2008;13(3):353–367. http://dx.doi.org/10.1080/13562510802045394

33. Wolff K. Flexible pacing: Aiding students to adapt to the complexities of multidisciplinary higher education. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

34. Potgieter M. Conceptual gain in first-year chemistry: Is the gap addressed effectively? ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

35. Basson I. Addressing the school-university physics practical skills gap. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

36. Boughey C. 'Naming' students' problems: An analysis of language-related discourses at a South African university. Teach High Educ. 2002;7(3):295–308. http://dx.doi.org/10.1080/13562510220144798

37. Jacobs C. Mainstreaming academic literacy teaching: Implications for how academic development understands its work in higher education. South African Journal of Higher Education. 2008;21(7):870–881. http://dx.doi.org/10.4314/sajhe.v21i7.25748

38. Bradbury J, Miller R. A failure by any other name: The phenomenon of underpreparedness. S Afr J Sci. 2011;107(3–4):112–119.

39. Morrow W. Epistemological access in the university. AD Issues. 1993;1(1):3–4.

40. Jacobs C. Towards a critical understanding of the teaching of discipline-specific academic literacies: Making the tacit explicit. Journal of Education. 2007;41:59–82.

41. Wolmarans N, Shaw C. Student conceptions of civil engineering in an Engineering I course. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

42. Marshall D, Case JM. d/Discourse in the learning of physics: The design of an introductory physics curriculum. African Journal of Research in Mathematics, Science and Technology Education. 2010;14(2):15–27.

43. Hurst E. Language in Engineering and the Built Environment: Examining student problems and impacts. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

44. Case JM. Knowledge matters: Interrogating the curriculum debate in engineering using the sociology of knowledge. Journal of Education. 2011;51:73–92.

45. Council on Higher Education. Proposals for undergraduate curriculum reform in South Africa: The case for a flexible curriculum structure. Pretoria: Council on Higher Education; 2013.

46. Jones S. Teach the ones you're with. American Physical Society News. 1995;4(7). Available from: http://www.aps.org/publications/apsnews/199507/teach.cfm

47. Tinto V. Leaving college: Rethinking the causes and cures of student departure. Chicago: University of Chicago Press; 1993.

48. Smit R, Wolmarans N. Student voice in 'the transition to university' problem. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

49. Vosloo MM, Blignaut S. From hero to zero…and back? The journey of first year access students in mainstream programmes. ASSAf Mind the Gap Forum; 2010 October 21–22; Cape Town, South Africa. Available from: http://www.assaf.co.za/stem-mind-the-gap-forum/

50. Boyer EL. Scholarship reconsidered: Priorities of the professoriate: Stanford, CA: Carnegie Foundation for the Advancement of Teaching; 1990.

51. Bowden J, Marton F. The university of learning. London: Kogan Page; 1998.

52. Wieman C, Perkins K, Gilbert S. Transforming science education at large research universities: A case study in progress. Change. 2010;42(2):7–14. http://dx.doi.org/10.1080/00091380903563035

53. Wieman CE. Why not try a scientific approach to science education? Change. 2007;39(5):9–15. http://dx.doi.org/10.3200/CHNG.39.5.9-15

54. Gaffney JDH, Richards E, Kustusch MB, Ding L, Beichner RJ. Scaling up education reform. Journal of College Science Teaching. 2008;37(5):48.

55. Brett P, Nagra J. An investigation into students' use of a computer based social learning space: Lessons for facilitating collaborative approaches to learning. Brit J Educ Technol. 2005;36(2):281–292. http://dx.doi.org/10.1111/j.1467-8535.2005.00457.x

56. Bourdieu P, Wacquant L. The state nobility: Elite schools in the field of power. Palo Alto, CA: Stanford University Press; 1998.