The ethics of curriculum development

Engineers and technicians in a context of development

Chris Winberg[1], Penelope Engel-Hills
Cape Peninsula University of Technology
Cape Town, South Africa
[1]winbergc@cput.ac.za

Simon Winberg
University of Cape Town
Cape Town, South Africa
simon.winberg@uct.ac.za

Arie Rip
University of Twente
Enschede, Netherlands
a.rip@utwente.nl

***Abstract*—South African higher education has, for the last twenty years, attempted to confront the legacy its past, particularly the lack of access to science, technology, engineering and mathematics-based (STEM) education by the vast majority of potential students. The current policy environment is dominated by a drive towards high skills jobs and innovation that links research to new forms of production and new services. With the promulgation of a new 'Higher Education Qualifications Sub-framework' (HEQSF, 2013) in South Africa there has been considerable curriculum development work across a number of fields and disciplines to enable the 'high skills' agenda. Many programs that served as entry qualifications to employment as computer engineering technicians have been subject to upward re-curriculation towards engineering programs. A concern is the lack of clarity around appropriate qualifications and skills levels for a developing country and what might differentiate engineering technician programs from professional engineering programs. There are deep concerns in South Africa about the need to transform society, in particular to ensure that the legitimate aspirations of black South Africans are met and that talented young citizens are able to access higher education and obtain qualifications that enable them to enter the workplace and contribute meaningfully to development. In this paper we discuss the ethics of curriculum development, and argue for an ethical framework to assist institutions to guide curricular decision-making in engineering. A methodology for curricular comparison was developed from the work of Karl Maton on 'semantic waves' that was used to construct a systematic comparison between a technician and engineering programme in the field of computer engineering. We show distinct knowledge differences between two programs, one a technician's diploma and the other an professional engineering degree program. We use the findings to illustrate wider concerns about the ethics of/in engineering curriculum development in South Africa as a developing country with a transformation agenda.**

Keywords—curriculum renewal; skills shortages; engineering professions; development contexts.

I. BACKGROUND: ENGINEERS AND TECHNICIANS IN SOUTH AFRICA

There is a shortage of all engineering professionals in South Africa, which has only one engineering professional per 3,166 capita [7]. This is much lower than comparable countries such as Brazil (1:227) or India (1:157) [8]. The shortage can in part be attributed to the country's apartheid past, which denied black South Africans access to the engineering professions. In post-apartheid South Africa there has been an effort to increase the number of black engineering professionals. There are three main types of engineering professionals in South Africa: engineers, engineering technologists and engineering technicians [6]. The designation depends on the post-school qualification that has been attained. Engineers and technologists usually hold a four-year Bachelor's degree while technicians hold a three-year diploma. The ideal ratio of engineers, technologists and technicians has been debated for years. The Engineering Council of South Africa (ECSA) recommends a 1:1:4 ratio [3], although actual figures suggest a 1:0.4:1.4 ratio [7]. Because of the low numbers of computer engineering technologists in South Africa, this group has been omitted from this paper). Research in the specific field of computer engineering suggests a greater need for technicians, due to the fact that South Africa is a user (and adaptor) of advanced technology rather than a technology innovator, and there is thus a concomitant need for technicians to implement, use, and modify the source technology appropriately [1]. The engineering profession has specifically raised concerns about employment arrangements brought about by the shortage of technicians on the one hand, resulting in engineers having to do technician-level work; as well as the shortage of engineers, resulting in technicians having to do engineering work - which is of greater concern [7].

A. *Engineering demographics*

Much has been achieved in post-apartheid South Africa with regard to the representation of black South Africans in the engineering professions. Current surveys suggest that black

978-1-4799-4992-2/14/$31.00 ©2014 IEEE

South Africans comprise ±30% of all professional engineers and ±40% of all engineering technicians [6]. While still not demographically representative, these trends are encouraging. The low numbers of black South African school leavers that meet the entry requirements in mathematics and science continue to prevent their access to engineering programs, and the lower academic requirements for diploma programs might explain the higher representation of black South Africans in the technician group. Women are particularly under-represented in engineering, with the profession characterized as 15% female 85% male [6]. A major shortage of older and experienced professionals has also been noted: only 13% of engineers are over the age of 50 [8], which has implications for the supervision of young engineers [4]. Throughput rates (i.e., achieving a qualification in the minimum time) in both engineering and technician programs are 'low and slow', with only approximately half of any first year student cohort completing the engineering program that they entered [3].

B. *Ethical issues for curriculum development*

University-based computer engineering programs in South Africa are strongly influenced by international accords (such as the Washington Accord for engineers and the Dublin Accord for technicians) [1] and by international standards (e.g., ABET, ACM & IEEE) [2]. While this international orientation ensures high standards in training, the amount of material placed in the disciplinary 'core' is extensive and leaves little room for local-orientated content [2]. South African computer engineers and technicians are thus more likely to meet the needs of users in the developed world than the needs of local communities. Students in engineering and technician programs come from diverse backgrounds and many understand the needs of local communities and are eager to use their engineering skills to address these needs [5]. The ethical issues that this paper addresses include how programs might promote computer engineering in an African context, and secondly, how the social and technical abilities of the diverse student population can be leveraged to address, and find solutions to problems that arise in local user communities. The South African Council of Higher Education has promulgated a new Higher Education Qualifications Sub-Framework (HEQSF) that presents opportunities for curriculum renewal in computer engineering and technician programs, with a view to developing engineers and technicians who can address needs in a context of development and change. ECSA was elected to chair the Committee on Engineering Capacity Building for the period 2012-2015 at the World Federation of Engineering Organizations' General Assembly – opportunities are thus provided for collaboration between ECSA, WFEO and UNESCO on various initiatives related to engineering capacity building across the African continent for the promotion of successful and sustainable development. Curricula arising out of such opportunities have the potential to address noted tendencies towards blurring the roles of engineer and technician in contexts where engineering skills are in short supply [7], and in particular to address the undervaluing of technicians [6]. Curricula should also provide talented young technicians with access, choices and pathways to professional engineering programs – without creating false expectations about the challenges of entering such programs.

II. METHOD: UNCOVERING THE ETHICS OF CURRICULUM

Engineering and technician program are related, but differ in important ways. Engineering programs focus on theory and conceptual design, while engineering technician programs focus on application and implementation [10]. Also, professional engineering programs typically require additional, higher-level mathematics, including multiple semesters of calculus and calculus-based theoretical science courses [3]. Technician programs typically focus on algebra, trigonometry, applied calculus, and other courses that are more practical than theoretical in nature [11]. Figure 1 shows the differences between theory/conceptual design and implementation/ application in the engineering professions, as well as the potential relationships and pathways between the different professional groups.

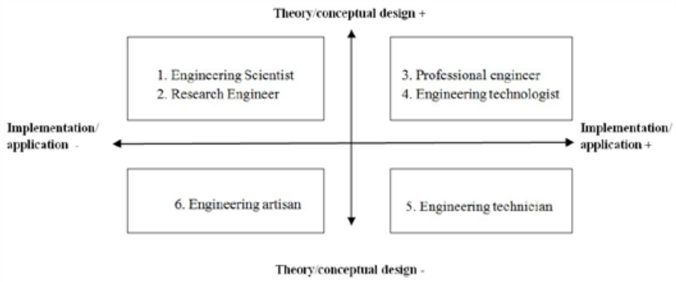

Fig. 1. A model of the engineering professions

The curricula of computer engineering (4 year degree) and computer systems technician (3 year diploma) programs were analyzed with a view to distinguishing the theoretical/ conceptual design and implementation/application elements, to study their similarities and differences. The program descriptors were verified by a range of academic and professional engineers and technicians then mapped over the four-year (eight semester) engineering and the three-year (six semester) technician programs respectively. The resultant 'sematic waves' [9] highlight the similarities and differences between the two programs. Semantic waves represent 'cumulative knowledge-building activities over time' [9] and mapping the movement of theory-based and practice-based learning identifies broad trends in educational programs. The data generated was used to uncover wider concerns and ethical aspects of curriculum development, in particular the tendency for technician programs to transition to engineering programs.

III. RESULTS

A. *The Computer Engineering program*

The computer engineering program studied required students to attain the following key outcomes:

- Identify, assess, formulate and solve convergent and divergent computer engineering problems creatively and innovatively;
- Apply knowledge of mathematics, basic science and engineering sciences from first principles to solve computer engineering problems;

- Perform creative design and synthesis of components, systems, engineering works, products or processes;
- Plan and conduct investigations and experiments;
- Use appropriate engineering methods, skills and tools, including those based on information technology;
- Communicate effectively, both orally and in writing, with engineering audiences and the community at large.
- Act professionally and ethically, exercise judgment and take responsibility within own limits of competence.

The above outcomes are achieved over a four year (or eight semester) program. The major outcomes are concerned with theoretical levels of understanding and the candidates' ability to accomplish the design of computer systems at the conceptual level. The subject areas – and assessment tasks in particular – were analyzed in order to find out the relative credit value given to theory and conceptual design versus implementation and application.

Table 1 shows the result of the analysis. Table 2 provides more detail and includes responses from research, academic and professional engineers who were interviewed.

TABLE I. DISTRIBUTION CREDIT VALUE ASCRIBED IN THE COMPUTER ENGINEERING CURRICULUM (TOTAL CREDITS 576, WITH WEIGHTING GIVEN TO PRACTICAL TRAINING 592*)

SUBJECT NAMES	Outcomes related to theory and/or conceptual design	Outcomes related to implementation and/or application	Credit value of theory and/or conceptual design	Credit value of implementation and/or application
Culture, Identity & Globalisation 1	+	-	8	0
Computer Science 1	+	-	36	0
Engineering Mathematics 1	+	-	32	0
Engineering Physics 1	+	-	32	0
Engineering Drawing 1	+	-	8	0
Engineering 1	+	-	32	0
Practical training 1	-	+	0	8*
Statistics in Engineering 2	+	-	12	0
Vector calculus for Engineers 2	+	-	16	0
Linear algebra for Engineers 2	+	-	16	0
Computer Science 2	+	-	48	0
Signals & Systems 2	+	-	12	0
Electrical Engineering 2	+	+	16	4
Electronic Engineering 2	+	+	16	4
Digital electronics 3	+	-	16	0
Signals & Systems 3	+	-	12	0
Operating systems 3	+	-	18	0
Embedded systems 3	+	+	10	10
System/network design 3	+	+	10	14
Control Engineering 3	+	-	10	0
Project management III	-	+	4	4
Practical training III	-	+	0	12*
Transmission lines IV	+	-	10	0
Digital systems IV	+	-	20	0
Digital signal processing IV	+	-	20	0
Process control & instrument IV	+	-	20	0
Wireless systems design IV	+	+	10	10
Control Engineering IV	+	-	10	0
New venture planning IV	+	+	4	4
Professional communication IV	+	+	4	4
Quality/maintenance mgt IV	+	+	6	6
Research project IV	-	+	20	24
TOTALS (32 subjects)	**28 /4-**	**12/20-**	**488**	**104**

TABLE II. THEORY/CONCEPTUAL DESIGN AND IMPLEMENTATION/APPLICATION IN THE COMPUTER ENGINEERING CURRICULUM

Implementation and application	Theory & conceptual design	Coding of response	Description of interviewees' responses	Example of interviewees' responses
I&A–	T&CD+	The fundamental core	A fundamental core of disciplinary knowledge underpins engineering, and needs to be protected in the curriculum.	*... the fundamentals: mathematics, physics, basic computing are non-negotiable ...* (Academic Engineer 1); *...I would strongly encourage any curriculum change to focus on providing a diverse range of ideas and experience rather than knowledge of any particular technology...* (Professional engineer 2).
		Essential professional expertise	Professional expertise includes disciplinary and field knowledge as well as professional values.	*I would very much like to see embedded-systems and lower level courses remain a big part of the ECE curriculum... While virtualization, virtual machines and dynamic languages are a big part of the industry landscape, a solid grounding in bits-and-bytes and the low-level functioning of a computer is still extremely important. All the abstractions we have built are leaky, and when those abstractions leak, a knowledge of low-level computing topics is indispensable* (Professional Engineer 3).
		Specific techniques and tools	Application contexts, or simulated work conditions within the curriculum, together with the application of tools and technologies related to solving problems in context should be of a sufficiently complex nature.	'*... simple PWM ... and squeaking speakers are way too simple for third years'* (Professional engineer 4); '*... they should have exposure to signal processing techniques... and [come] up with their own algorithms*' (Professional engineer 3).
I&A +	T&CD-	Problem solving in context	Problem solving for real-time applications and exposure to solving problems using real-time operating systems	'*…taking responsibility for project work….*' (Professional Engineer 5), '*…able to do time planning ... and use of Gantt charts ... produce parts lists ... and work with budgets*' (Research engineer 3).

TABLE III. DISTRIBUTION CREDIT VALUE ASCRIBED IN THE COMPUTER SYSTEMS TECHNICIAN CURRICULUM (TOTAL CREDITS 360)

SUBJECT NAMES	Outcomes related to theory and/or conceptual design	Outcomes related to implementation and/or application	Credit value of theory and/or conceptual design	Credit value of implementation and/or application
Electronics 1	+	-	8	2
Digital systems 1	+	+	5	5
Mathematics 1	+	-	10	0
Electrical Engineering 1	+	-	10	0
Communication Skills 1	+	-	0	5
Computer Skills 1	-	+	0	5
Programming 1	-	+	6	4
Electrical Engineering Practice 1	+	-	0	10
Digital systems 2	+	+	5	5
Network Systems 1	+	-	9	1
Programming 2	-	+	4	6
Systems Analysis 1	+	-	9	1
Mathematics 2	+	-	10	0
Database Principles 1	+	-	8	2
Design Project 1	+	+	5	5
Projects 2	+	+	5	5
Software Engineering Practice 1	-	+	0	60
Database Principles 2	+	-	8	2
Network Systems 2	+	-	8	2
Programming 3	-	+	4	6
Digital Systems 3	+	+	5	5
Systems Analysis 2	+	-	9	1
Signal Processing 1	+	-	8	2
Design Project 2	+	+	5	5
Software Engineering 1	+	-	8	2
Operating Systems 1	+	-	7	3
Software Engineering Practice 2	-	+	0	60
TOTAL (27 subjects)	6/27	12/27	156	204

TABLE IV. THEORY/CONCEPTUAL DESIGN AND IMPLEMENTATION/APPLICATION IN THE COMPUTER SYSTEMS TECHNICIAN CURRICULUM

Implementation and application	Theory and conceptual design	Coding of response	Description of response	Example of response
I&A+	T&CD-	The fundamental core	Algebra, trigonometry, applied calculus and engineering science underpin the technician curriculum.	*'…it' s important that t[the students] also include methodical work on problems … formulating hypotheses for possible solutions … and … synthesizing partial solutions … so that they … not only test and evaluate the prototype … but they think about it scientifically (Academic Engineer, teaching technicians).'…the biggest problem with the curriculum here is that it does not establish a sound mathematical basis in students…the mathematical sciences have been eroded with time and it's being done by people that felt maybe threatened by it or whatever the reason is. … I call it a dilution …(Dean, Technical Faculty)*
		Technical expertise	Technical expertise involves implementation, application and adaptation of advanced technologies	*'Good technicians can make adjustments from the point of view of usability and practicality…' (Engineering technician).*
I&A-	T&CD+	Specific techniques and tools	Keeping up-to-date with technology	*'If the developing world is to take ownership of FOSS [free and open software] we will have to address such issues of technical skills and useful and useable software… '(Academic engineer).*
		Solving technical problems in actual workplace contexts	Experiential learning in appropriate workplaces, supervised by professional engineers and technicians.	*'[Students should develop] the kinds of skills that are needed in the private sector: project management, setting specifications, design and implementation, cost estimates, etc. Such a complete experience is difficult to achieve within a practical university project, in my experience' …(Professional engineer)*

The theoretical/conceptual design elements and the implementation/application elements were then mapped over the eight semesters. The solid line in Figure 2 represents the theoretical/conceptual design outcomes over the four years of the program; the dashed line represents the implementation/application outcomes over the same period. The rise in theoretical/conceptual design complexity in the final year represents new, elective areas of specialization.

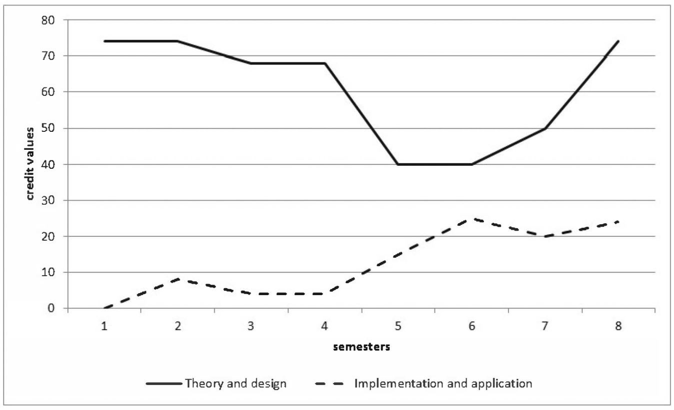

Fig. 2. Semantic waves representing theoretical and conceptual design vs implementation and application in the Computer Engineering Program.

B. *Computer Technician program*

Computer engineering technician programs offered at South African universities require qualifying students to attain the following outcomes:

- Communicate, develop, maintain and implement software systems;
- Develop, implement and maintain hardware systems in the computing environment;
- Implement and maintain network hardware and operating systems;
- Describe and implement the theoretical principles supporting the computing environment.

There is a notable absence of professionalism ethics in the Technician program, which is of concern.

Table 3 shows the larger weighting awarded to the practical training in the technicians' program. While this is to be expected, there are concerns that the credit value of the experiential (or workplace learning) components (120 credits in total) is too high [4] and that the level of the theory and design-based components is too low [11]. While some interviewees supported the practical orientation of the technicians' program, which can be seen in the dominance of the dashed line representing the implementation/application focus of the program (Figure 3), there were some concerns raised – as in the examples provided in Table 4.

IV. CONCLUSION

The study shows that curricula in the two different types of engineering qualifications differ in the extent to which they provide students with theory and conceptual design and implementation and application skills as a consequence of the way the two curricula are structured. Strengthening the technician program in the areas of engineering mathematics, physics and science would provide students on these programs with access to theoretical knowledge [9]. This provision is more likely to enable talented technicians to access professional engineering programs and is thus ‘a question of distributional justice’ [11].

The inclusion of community-based projects in the professional engineering curriculum would ensure that this curriculum remains relevant and responsive to the demands of professional practice in contexts of development [2], and flexible enough to cater to a diverse student intake. Computer engineering innovation, when applied with too narrow and technical a focus, produces applications suitable for developed countries instead of solving local problems [1]. Engineering and technician programs need to ensure a strong, competent, growing, sustainable and representative engineering profession, able to provide the expertise necessary for the needs of the country and to exert a positive influence in South Africa.

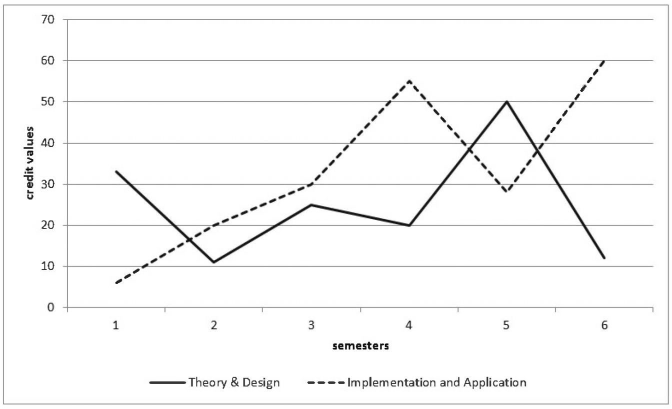

Fig. 3. Semantic waves representing theoretical and conceptual design vs implementation and application in Computer Systems technicians program.

REFERENCES

[1] E. Blake,“Software engineering in developing communities,” CHASE ’10: Proceedings of the 2010 ACM/ICSE Workshop on Cooperative and Human Aspects of Software Engineering, pp. 1-4, New York, NY, USA, May 2nd2010.

[2] E. Blake and W. Tucker,“Socially Aware Software Engineering for the Developing World,”P. Cunningham and M. Cunningham (Eds.) IIMC International Information Management Corporation, Conference ProceedingsIST-Africa, 2006.

[3] Engineering Council of South Africa (ECSA). Annual Report: 2011/2012. Available at: https://www.ecsa.co.za/news/Annual%20Reports/ECSA_Annual_Report_2011-12.pdf

[4] H. Hanrahan,“A Nationally Integrated Model for Qualifications, Registration and Licencing in the Engineering Profession,” presented at the 22nd Annual SA Engineering Education conference, 10 October 2000.

[5] J. Jawitz and J. Case,“Exploring the reasons South African students give for studying engineering,”Int. J. Engng Ed. Vol. 14, No. 4, pp. 235-240, 1998.

[6] R. du Toit and J.Roodt, “Engineers in a developing country: the profession and education of engineering professionals in South Africa,” Pretoria, South Africa: Human Sciences Research Council Press, 2009.

[7] R. du Toit and J.Roodt ,“Engineering professionals,” J. Erasmus and M. Brier (Eds.) “Skills shortage in South Africa: case studies of key professions” Cape Town, South Africa: HSRC Press, pp. 75-112, 2009.

[8] Magnet Communications. Magnet Professional Survey 2011: Engineering/Technology vs. Total All Professionals - South African Edition. Available at: https://www.ecsa.co.za/news/Surveys%20PDFs/310812_PartnerPres_ECSA.pdf

[9] K. Maton, “Knowledge and knowers,” London: Routledge, 2013.

[10] UNESCO,“Engineering: Issues, challenges, and opportunities for development”, 2010. Available at http://unesdoc.unesco.org/images/0018/001897/189753e.pdf

[11] L.Wheelahan,“From old to new: the Australian qualifications framework,” Journal of Education and Work, Volume 24, Issue 3-4, 2011.