World Transactions on Engineering and Technology Education
Vol.2, No.2, 2003

North-South collaboration advancement on engineering education through the Conceive-Design-Implement-Operate (CDIO) initiative

Zola Mbanguta

Linköping University, Linköping, Sweden
National Department of Education, Pretoria, South Africa

ABSTRACT: As South Africa has just declared Outcomes-Based Education (OBE) as a national policy, some of the world's leading universities are reforming engineering education to have more of an outcomes-based approach through the four aspects of *curriculum*, *teaching and learning*, *assessment* and *workshop/laboratory equipment*. This article gives a background to the South African vision on OBE, critically reviews the literature on the Conceive-Design-Implement-Operate (CDIO) initiative and on skills transfer, and explores the action research methodology-based study and its findings. The article also makes recommendations for a North-South CDIO Initiative Skills Transfer Programme Model through the UNESCO International Centre for Engineering Education (UICEE) African regional satellite centres and other major universities that should be given the necessary support to become CDIO Initiative Centres. These centres should collaborate directly with the North through an academic degree-based sandwich programme on engineering education and must, in turn, carry the burden of supporting other smaller Southern universities for a common African engineering education vision. This will gradually bridge the North-South gap in engineering education.

INTRODUCTION

The United Nations Educational, Scientific and Cultural Organization (UNESCO) acknowledged that the second half of the last century would go down in the history of higher education as the period that saw the gap between the industrially developed countries and the developing countries, with specific reference to the least developing countries, becoming wider with regard to access and resources for higher learning and research [1].

It is for this reason that the World Bank advised the developing countries to institute policies that would enable them to narrow the gaps that separate them from the rich countries [2]. It is for that reason that a tool has been forged for that development, which strengthens international cooperation and is based on a very strong belief that North-South cooperation programmes could assist developing countries in overcoming practical obstacles to sustainable development [3].

NATIONAL OUTCOMES-BASED EDUCATIONAL POLICY IN SOUTH AFRICA

South Africa has taken a bold move by introducing Outcomes-Based Education (OBE) as a national policy. OBE was introduced in the General Education and Training (GET) band, which comprises the first nine years of schooling in 1997. The end of 2002 saw the first graduates of the new system obtaining their GET Certificates. It is expected that the Further Education and Training (FET) band, which comprises the last three years of schooling, will start implementing OBE soon.

The National Human Resource Development Strategy states that the South African people will be provided with a solid educational foundation for social participation [4]. Further, they will also be empowered to develop the relevant and marketable skills at further and higher education levels. The *National Plan of Higher Education* led to the release of *An Academic Policy for Programmes and Qualifications in Higher Education* [5]. This policy states that:

> *It is crucial to equip all graduates with the skills and qualities required for participation as citizens in a democratic society and as workers and professionals in the economy. This should not be seen in a simplistic vocational sense as there is increasing evidence to suggest that narrowly technical skills are becoming less important than knowledge management and organisational skills. What evidence there is suggests that employers, in addition to technical skills, want graduates who can demonstrate a strong array of analytical skills and a solid grounding in writing, communication and presentation skills* [6].

The Plan adopts Gibbons' skills requirements [7]. These must underpin all graduate education in South Africa, and include computer literacy, knowledge reconfiguration skills, information management, problem solving within an application context, teambuilding, networking, negotiation and mediation competences and social sensitivity.

THE CONCEIVE-DESIGN-IMPLEMENT-OPERATE INITIATIVE: AN OUTCOMES-BASED EDUCATIONAL FRAMEWORK

The Conceive-Design-Implement-Operate (CDIO) initiative is an innovative outcomes-based educational reform framework for producing the next generation of engineering leaders. Its impact has already been felt by Northern universities. It is based on a simple concept that, because graduating engineers are expected to appreciate engineering *processes*, to be able to

contribute to the development of engineering *products*, and to do so while working in an engineering *organisation* while developing as *whole*, *mature* and *thoughtful individuals*, the approach to the CDIO syllabus is based on the essential functions of engineering that graduating engineers. These core functions cover the concepts of **c**onceive-**d**esign-**i**mplement-**o**perate, facilitating complex value-added engineering systems and products in a modern team-based environment [8].

The strategy to implement the CDIO Initiative has four themes. Engineering education reform takes place in the CDIO skills-based *curriculum* first, that is underpinned by a deeper working knowledge of technical fundamentals in order to ensure that it addresses the appropriate material necessary in order to conceive and build successful systems and products. The curriculum is guided by three innovative curricula structures, namely: the *cornerstone* that motivates students to be engineers by introducing engineering experiences and exposing them to essential early skills that lead to building something; the *conventional disciplinary subjects* that are better coordinated and linked to demonstrated practice required by engineering; and the *capstone* that includes a substantial experience in which students design, build and operate a product/system. Student projects, internships and co-ops are integrated extensions of the overall learning experience [9].

Second, an improved *pedagogy*, that takes into account students' prior experience and its effects on learning must complement the new curriculum. Areas of CDIO skills concentration include an increase in active and hands-on learning, an emphasis on problem formulation and solution, and an greater focus on concept learning and the enhancement of learning feedback mechanisms.

Third, it has been recognised that the key to educational improvement is to develop an effective *assessment* scheme so that the progress of students and improvement in the quality of education provided can be tracked. The CDIO Syllabus codifies 80 identifiable attributes as important assessment statements of learning objectives for graduates. The assessment tools embrace creativity, design and entrepreneurship and include portfolios, design reviews and desk critiques while students become more responsible for not only learning but also for self and peer assessment. Attitudinal change and skill progression are assessed [10].

Finally, as in the CDIO initiative, engineers design and build products and systems so as to enhance integrated theory-practice or knowledge-application concepts; *modern engineering workshop/laboratories* that are conducive to this approach must be developed. By providing students with repeated authentic design-build experiences, they develop and reinforce a deep working knowledge of the fundamentals and learn the skills in order to design and develop new products and systems.

Experiences in conceiving, designing, implementing and operating are woven into the curriculum, particularly in the introductory cornerstone and concluding capstone. The capstone potentially expands into a multi-semester experience, more closely linked to disciplines. This results in students designing, building and operating a product.

With theory development paralleling practical implementation, students learn both the applicability and limitations of theory. If students are to understand that conceiving, designing, implementing and operating is the context of the education, then it is desirable that workshop/laboratories are developed and constructed that are supportive of and, in fact, are organised around Conceive-Design-Implement-Operate [11][12].

Two types of workshop/laboratories are a basic requirement for a CDIO initiative-based approach. Firstly, the creation and staffing of *browsing laboratories* provides areas where preassembled experiments can be operated by students with technical supervision to reinforce or supplement the concepts learned in the classroom. Secondly, the *Industrial Design Engineering Studio* is an essential element in the CDIO approach of systems and products [13]. The Industrial Design Engineering Studio is a laboratory to support teams working with virtual prototypes and a physical prototype workshop where engineering projects of significant scope are developed by students.

The Conceive-Design-Implement-Operate Syllabus

As all engineers recognise that a product or process is more likely to meet the needs of the customer if designed to a well-developed set of requirements, the CDIO syllabus is structured as shown in Table 1 [14].

Table 1: Structure of the CDIO syllabus [14].

1. Technical Knowledge and Reasoning	1.1 Knowledge of Underlying Sciences 1.2 Core Engineering Fundamental Knowledge 1.3 Advanced Engineering Fundamental Knowledge
2. Personal and Professional Skills and Attributes	2.1 Engineering Reasoning and Problem Solving 2.2 Experimentation and Knowledge Discovery 2.3 System Thinking 2.4 Personal Skills and Attitudes 2.5 Professional Skills and Attitudes
Interpersonal Skills	2.6 Teamwork 2.7 Communications
3. Conceiving, Designing, Implementing and Operating Systems in the Enterprise and Societal Contexts	3.1 External and Societal Context 3.2 Enterprise and Business Context 3.3 Conceiving and Engineering Systems 3.4 Designing 3.5 Implementing 3.6 Operating

RATIONALE AND AIM OF THE RESEARCH

The rationale is the release of an Academic Policy for Programmes and Qualifications on Higher Education in South Africa, which has declared Outcomes-Based Education (OBE) as a national policy. This recognises the country's high international status on engineering education through its membership of the Washington Accord and International Engineers' Mobility Forum [15].

The research aims to transform the CDIO initiative into a programme that could be registered on the National Qualifications Framework (NQF) for use in South Africa. Through South Africa's membership of the SADC Protocol on Education and Training and leadership of the African Union, the programme could be transferred to the rest of Africa through the proposed model.

RESEARCH METHODOLOGY

As outlined previously, the research arose out of the newly released South African OBE policy, which is underpinned by an international benchmarking obligation against the world's best practices. Also, having analysed the rationale and stated the aim of the research, the general approach to the research was considered.

Action research, interviews and observations were used as methods over a one year period as Trow, quoted in Burgess, alluded to the use of more than one research method in one study [16]. As the aim of the CDIO initiative is to introduce outcomes-based approaches to engineering education, action research was an option as it is also a means of injecting additional or innovatory approaches to teaching and learning into an ongoing system that normally inhibits innovation and change. At the same time, it equips teachers with new skills and methods, thus sharpening their analytical powers and heightening self-awareness [17].

The researcher, working collaboratively with the CDIO Initiative Team and in consultation with his South African counterparts, developed a plan of critically informed action as guided by Kemmis and McTaggart's four fundamental aspects of plan, action, implementation and reflection in action research [18]. A plan was conceived and consisted of a developed CDIO theoretical framework, which was aligned to the South African national outcomes-based education policy, as well as a plan of action for the North-South CDIO skills transfer.

The action stage consisted of interviews and observations with the CDIO Initiative Team on the CDIO Skills Transfer Programme Model, while at the same time data was gathered on the state of readiness of South African universities. The researcher also published an article on the CDIO initiative with the University of Cape Town Centre for Research in Engineering Education to advance the Southern African engineering education community's awareness.

The next step was the implementation of the plan that was based on the presentation of the developed North-South CDIO Skills Transfer Programme Model to the CDIO Initiative Team. At the same time, this Model was communicated to South Africa and a team was set up to work on the CDIO Initiative in South Africa.

The researcher also opened discussions with the UNESCO International Centre for Engineering Education (UICEE) regional satellite centres in Africa, with a view to have the CDIO initiative discussed as a part of the greater African engineering education agenda. The reflection stage of action research indicates that South Africa and one of the UICEE regional satellite centres in Africa have set up teams to work with the CDIO Team on collaborative research with a view to becoming the CDIO Initiative Centres in Africa. This is the actual internationalisation of the CDIO initiative, so as to be a part of the greater African engineering education agenda.

FINDINGS AND DISCUSSIONS

The intended outcome of the research was to develop a North-South CDIO Initiative Skills Transfer Programme Model. South Africa would be the nation that the programme would be designed for by virtue of its clearly spelt out national OBE policy and its influential position in not only the African, but also the world's engineering education. The research was designed such that as it was based in Sweden, direct contact with South African universities, who were later joined by other African universities, enabled a programme that could be directly influenced by the South.

An initially discussed model recommendation was made, that a non-credit bearing CDIO initiative training programme be developed for the training of Southern university engineering educators and that the existing engineering master degree programmes at CDIO initiative universities be offered to advance their academic knowledge.

However, the main strength of action research was in small-scale intervention, while allowing for a closer examination of the effects of such intervention [19]. Attention was also drawn to the fact that:

- South Africa has put in place the National Qualifications Framework (NQF) through the promulgation of the South African Qualifications Authority Act of 1995, which ensures an integrated national framework for learning achievements, facilitation of access to, and mobility and progression within, education training and career paths, the enhancement of the quality of education and training, acceleration of the redress of past unfair discrimination in education, training and employment opportunities; and thereby contributing to the full personal development of each learner and the social and economic development of the nation at large. Therefore, the education and training offered to South Africans must be credit-based and lead to a full qualification recognised in South Africa [20].
- Existing engineering programmes at CDIO initiative universities are not outcomes-based programmes and, as such, new CDIO skills-based programmes should be developed to advance engineering educators knowledge on outcomes-based engineering education.

With regard to skills transfer, Lambert warns against training offered to employees that is not in line with the employer's training policy, as there may be no rewards or incentives for it, opportunities to apply what has been learned could be denied and that the employer is not able to help when difficulties and problems arise [21]. He further warns that the training method is often inappropriate to the material learned and that its objectives are often unclear and quantifiable behavioural

outcomes are not specified. Shepherd suggests that, as skills transfer cannot be assumed to occur, it therefore requires that explicit attention be paid during the learning process and also during the act of transfer itself [22]. Therefore, he proposes two models: a skills acquisition model and a skills transfer process model.

Eceim advises for a periodic programme review to steer a mentoring process and that a periodic re-examination should take place in order to check comprehension while also ensuring a mastery of the skills presented [23]. Wesseling and Lundberg stress that any North-South collaboration should aim distinctly at the augmentation of human knowledge and skills transfer and that it should be linked to academic training that leads to the awarding of research degrees at the Masters and doctorate levels [24]. They further emphasise the importance of the sandwich model in which research in the South alternates with short periods of training in the North.

RECOMMENDATIONS

After the performance of a general assessment of the current skill level of engineering educators, which revealed that an average number of them possess a Bachelors degree in engineering education, the researcher therefore recommends a collaborative research-based partnership that entails the following characteristics:

- CDIO Initiative-based Master and doctoral degree programmes in engineering education to be developed, which would retrain engineering educators into outcomes-based approaches while also advancing research into cognitive-design-implement-operate as an engineering educational philosophy.
- These research degrees be offered by the North CDIO initiative universities.
- These research degrees be registered on the NQF and Council on Higher Education in South Africa before the commencement of any training involving South Africans. This would also allow for the development of capacity for the programme's sustainability in South Africa and Africa while, at the same time, South universities with the relevant infrastructure, can also offer them.
- Research will be South-based while training sessions will be attended in the North universities.
- The teaching and learning module for the South African FET engineering educators, developed by Makgato and Mbanguta, be registered under these programmes for credits that lead to full qualifications [25].

The North-South CDIO Initiative Skills Transfer Programme Model is as follows:

- South universities that are have UICEE regional satellite centres, as well as other major universities with better facilities that meet the basic CDIO initiative requirements, gain appointments as CDIO centres and collaborate directly, and on an equal basis, with the North. Support will be sought so that they are adequately equipped and that equipment gets updated regularly to promote the responsibilities of elevating regional engineering education standards through staff retraining programmes so that would be fairly comparable to those of the North.
- Other South universities affiliate directly to the regional CDIO centres.
- A central South office be established and supported for the specific responsibility of coordinating research, conducting seminars and conferences, as well as disseminating information to others.
- An annual North-South CDIO initiative international conference be held with the main aim of sharing information, research and development progression and the way forward.

CONCLUSION

The World Bank, UNESCO and regional unions of government data have always confirmed the gap in the education and training resources available between the North and the South. During the past academic year of this research, the researcher has also interviewed students in engineering education schools and departments of universities located in the North. Data shows that the European and American students interviewed demonstrated high mastery of skills with regard to the operation of equipment, which has led to the design and building of new products and systems as required by the programme.

However, the same cannot be said about the African and Asian students whom the researcher interviewed at two North universities, who had obtained their Bachelor of Engineering degrees in their home countries and had been admitted into Master degree programmes by the North universities. These students revealed that they had joined the programmes with more theoretical and less application experiences because of the lack of resources (equipment and, in some cases, the entire workshop/laboratory) in their South universities.

North-South collaboration on engineering education should be intensified so as to promote and leave a legacy in developing countries, particularly in the key areas of system/product development, manufacturing, assembly and maintenance. This will also require a constant check and updating of workshop and laboratory equipment [26].

Conceiving-Designing-Implementing-Operating systems in the enterprise and societal contexts requires underpinning of technical knowledge and reasoning skills, personal and professional skills and attributes, interpersonal skills. It is directly linked to well-equipped workshop/laboratories for integrated knowledge and its application, while also taught, learned and assessed in a unique manner. If the philosophy of offering engineering education programmes can be based on the CDIO approach, the gap between North and South can be bridged within 10 to 20 years.

REFERENCES

1. UNESCO, *World Conf. on HE: World Declaration on HE for the 21st Century and a Framework for Priority Action for Change and Development in HE*. Paris: UNESCO (1998).
2. World Bank, *World Bank Report: Knowledge for Development - Including Selected World Development*. New York: Oxford University Press (1998).
3. UNCTAD, Technical Cooperation: Meeting the Development Challenge. Paris: UNCTAD (2002).
4. RSA Government, HRD Strategy: A Nation at Work for a Better Life for All. Pretoria: Government Printer (2001).

5. Department of Education (DoE), National Plan for Higher Education. Pretoria: DoE (2001).
6. Department of Education (DoE), An Academic Policy for Programmes and Qualifications in HE. Pretoria: DoE (2002).
7. Gibbons, M., *Higher Education Relevance in the 21st Century*. Washington, DC: The World Bank (1998).
8. Crawley, E.F., The CDIO syllabus: a universal template for engineering education. *Proc. ASEE/IEEE Frontiers in Educ. Conf.*, Boston, USA (2002), http://www.cdio.org/papers/creating_syll_fie.pdf
9. Gustafsson, G., Newman, D.J., Stafström, S. and Wallin, H.P., 1st year introductory courses as a means to develop conceive – design – implement – operate skills in engineering education programmes. *Proc. SEFI Annual Conf.*, Firenze, Italy (2002), http://www.cdio.org/papers/1styr_intro_courses.pdf
10. Darmofal, D.L., Söderholm, D.H. and Brodeur, D.R., Using concept maps and concept questions to enhance conceptual understanding. *Proc. ASEE/IEEE Conf.*, Boston, USA (2002), http://www.cdio.org/papers/concept_maps_fie.pdf
11. Malmqvist, J., Young, P.W., Östlund, S. and Berggren, K-F. and Crawley, E.F., Designing Design Education: An Approach Based on the CDIO Syllabus, http://www.cdio.org/papers/designing_education.pdf
12. Crawley, E.F., Hallam, C. and Imrich, S., Engineering the engineering learning environment. *Proc. SEFI Annual Conf.*, Firenze, Italy (2002), http://www.cdio.org/papers/learningenvironment.pdf
13. Norrström, J., The IDE Studio: Development of an Environment for Distributed Design Work. MSc Thesis (2001).
14. Berggren, K-F., Brodeur, D., Crawley, E.F., Ingermarsson, I., Litant, W.T.G., Malmqvist, J. and Östlund, S., CDIO: An international initiative for reforming engineering education. *World Trans. on Engng. and Technology Educ.*, 2, **1**, 49-52 (2003).
15. ECSA, ECSA and Transformation: Education, Standards and Procedures (2001), http://www.ecsa.co.za
16. Burgess, R.G., *Field Research: A Source Book and Field Manual.* London: Harper and Row (1982).
17. Cohen, L. and Manion,. L., *Research Methods in Education.* London: Routledge (1995).
18. Kemmis, S. and McTaggart, R., *The Action Research Planner.* Melbourne: Deakin University (1988).
19. Zuber-Skerrit, O., *Action Research in Higher Education: Examples and Reflections.* Brisbane: Griffith University (1992).
20. SAQA, *Regulations for Registration of Programmes and Qualifications.* Pretoria: SAQA (1998).
21. Lambert, T., Ten Reasons for Failure to Transfer Learning to the Workplace (1999), http://www.AxysSolutions.com
22. Shepherd, I.D.H., *Key Skills: teaching and learning for transfer.* London: DfEE (2000).
23. Eceim, Skills Transfer Strategies. www.eceim.ie/skills_transfer_strategies.htm
24. Wesseling, C. and Lundberg, I., North-South and South-South collaborations in OHS (2003), www.ufa.org
25. Makgato, M. and Mbanguta, Z., Towards an outcomes-based teaching and learning module for the teacher preparation programmes of FET institutions' engineering and technology educators in South Africa. *World Trans. on Engng. and Technology Educ.*, 1, **2**, 227-232 (2002).
26. Mbanguta, Z., Bolton, K. and Gustafsson, G., North-South collaboration in technological advancement: the Sweden-South Africa Engineering Education Collaboration project. *World Trans. on Engng. and Technology Educ.*, 1, **2**, 185-190 (2002).

UNESCO INTERNATIONAL CENTRE FOR ENGINEERING EDUCATION

7th UICEE Annual Conference on Engineering Education

The 7th Annual Conference of the UNESCO International Centre for Engineering Education (UICEE), under the theme *Educating for the Global Community*, will be held in Mumbai, Maharashtra State, India, between 9 and 13 February 2004. The Conference will be carried out in parallel with the *1st Annual Conference of the Monash Asia Institute* (MAI), based at Monash University, Melbourne, Australia.

The prime objectives of the Conference are to bring together partners, members, associates, students and supporters of the UICEE from all over the world and to continue discussion on issues of importance to engineering education. To debate the activities of the UICEE and to foster friendships already established are also important objectives of the Conference. Moreover, it is anticipated that the Conference will further enhance the UICEE's links and networks, and will set the stage for more innovative and collaborative ventures.

Mumbai in Maharashtra State, India, is one of the prime business, education and financial centres, as well as tourist destinations in India, and is quite rightly called *the Gate of India*. It is one of the most beautiful cities in India, which provides visitors with a unique, spectacular and picturesque environment.

The Conference theme, *Educating for the Global Community*, was chosen to identify and present best projects, programmes and examples relevant to the main theme, address issues of concern, and to discuss the status and quality of global engineering education. Although the Conference emphasis is on the main theme, paper proposals on all aspects of engineering education and industrial training are most welcome. Suggested topics for Conference papers include, but are not restricted to, the following:

- Innovation and best practice in engineering education
- Case studies and international examples of engineering education & training
- International collaborative programmes and systems
- International mobility of staff & students
- Recognition of foreign qualifications & accreditation systems
- The impact of new technology on the effective training of engineers & technologists
- Development of new curricula
- Effective methods in engineering education
- Multimedia in engineering education
- Management of academic engineering institutions
- Quality assurance in engineering education
- Engineering management education
- Promotion of continuing engineering education, distance education & open learning
- Academia/industry interaction programmes
- Social and philosophical aspects of engineering
- Articulation in engineering and education & credit transfer
- TAFE and vocational education & training

A number of well-known local and international experts will be invited to address the Conference on key issues of engineering education. Sessions will be structured to encourage useful discussion, and it is intended that such discussion will be summarised towards the end of the Conference. Proposals for the arrangement of invited sessions are welcome, and these sessions are expected to address topical issues in engineering education. There is also room for innovative formats, permitting flexible arrangements for poster sessions, group discussion and interaction, demonstrations, etc.

You can visit the UICEE's Conference website for more information and key deadlines at:

http://www.eng.monash.edu.au/uicee/meetings/index.html