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North-South collaboration on engineering education through CDIO educational theory reforms: the creation of an African CDIO knowledge society

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ABSTRACT: South Africa's international competitiveness on engineering products through internationally benchmarked engineering education with the world's best is its first priority following the release of *An Academic Policy for Higher Education Programmes and Qualifications* in 2002. South Africa is always reminded of a responsibility to empower not only itself, but the rest of the African continent through the African renaissance vision and the African Union's *New Partnership for Africa's Development* programme. In the article, the author gives a brief background on NePAD's vision and principles; explains the development of a Conceive-Design-Implement-Operate (CDIO) transfer model to the South, while also being adopted by the North for the worldwide spread of CDIO educational theory. The article concludes with the appointment of a South African university to establish an international CDIO centre for Africa, which will work directly with the other world leading universities on engineering education in spearheading reforms for CDIO educational theory to create a CDIO knowledge society in Africa. This follows recommendations made by seminar delegates participating at the *1st North African Region Seminar on Engineering and Technology Education*, held in September 2003.

INTRODUCTION

This article follows a number of others the researcher has published on North-South engineering education collaboration, one of which was published with two Swedish colleagues on a vision to bridge the development gap that separates the South from the North [1]. As clearly articulated in the previously published articles, this research was prompted by UNESCO's statement that the second half of the last century will go down in the history of higher learning and research as the period that saw the gap widen between industrialised nations and developing countries [2]. This was immediately followed by the World Bank's advice to developing countries that they should institute development policies that would narrow the gap between them and the industrialised nations [3].

This research was also prompted by the release of *An Academic Policy for Higher Education Programmes and Qualifications in South Africa* of 2002 that paved the way for an outcomes-based higher education system [4]. This was as declared by the South African Qualifications Authority for all education and training in 1997 and coincided with higher engineering education reforms in Europe and North America. Moreover, it is the researcher's own personal objective, as the officer then responsible for the technical education desk of the African National Congress (ANC) before South Africa's liberation in 1994 and the country's Chief Engineering and Technology Education Specialist after liberation, to reclaim South Africa's position as the tenth most industrialised nation in the world, and emphasise its intertwined commitment to the renaissance of Africa in engineering education [5].

The period UNESCO refers to as the increased gap between developed and developing countries is that time during which African countries gained their freedom and independence from colonisers. Does this imply that attaining independence was a fatal move for developing countries? Or does it imply that governments, academics and businesses of developing countries did not live up to expectations to ensure a smooth and successful transition to balance the higher education quality of developing countries?

AFRICAN LEADERS' RESPONSE: NEW PARTNERSHIP FOR AFRICA'S DEVELOPMENT

Immediately after the World Bank's advice that developing countries should institute policies that would enable them to narrow the gap between them and richer countries, Africa's leaders moved towards a total overhaul and revamp of the Organisation of African Unity (OAU). By July 2001, the African Union was established with the ultimate objective to replace the OAU and it immediately adopted the New Partnership for Africa's Development (NePAD) as a vision and strategic framework for Africa's development. NePAD is designed to address the current challenges facing the African continent, such as escalating poverty levels, underdevelopment and the continued marginalisation of Africa, which need radical intervention to develop a new vision that would guarantee the renewal of Africa [6].

NePAD's primary objectives include placing African countries, both individually and collectively, on a path of sustainable growth and development and to halt the marginalisation of Africa in the globalisation process and enhance its full and beneficial integration into the global economy. NePAD's principles include anchoring the development of Africa on its resources and resourcefulness of its people, fostering partnerships between and among African peoples, accelerating regional and continental integration, and forging a new international partnership that changes the unequal relationship between Africa and the developed world. NePAD's priorities include the following:

- Establishing conditions for sustainable development by ensuring regional cooperation and integration and capacity building;
- Introducing policy reforms and increased investment in the human development sectors with a focus on education, science and technology and skills development;
- Building and improving infrastructure, including information and communications technology, energy, transport, water and sanitation;
- Promoting the diversification of production and exports, particularly with respect to agro-industries, manufacturing, mining, mineral beneficiation and tourism;
- Accelerating intra-African trade and improving access to the markets of developed countries.

NePAD's immediate desired outcomes for human resource development include that Africa accelerates the pace of achieving set African goals, particularly human development; that Africa achieves the desired capacity for policy development, plus coordination and negotiation in the international arena to ensure its beneficial engagement in the global economy; and that genuine partnerships are established between Africa and developed nations based on mutual respect and accountability.

It is also important to recognise that the key problems in education in Africa involve the following key aspects:

- Poor facilities and inadequate systems under which the vast majority of Africans receive their training;
- The educational facilities in Africa are in a state of dilapidation and are non-functional;
- Graduates at all levels are unemployable because of the poor education quality they have received, thereby aggravating the problem of unemployment and poverty;
- Improvements have to be undertaken in curriculum development, quality improvements and access to information and communications technology (ICT);
- Under-investment in science and technology is the cause for the parlous state of affairs of declining or stagnating scientific and technological growth, thus resulting in the overall quality of education in Africa to continue to deteriorate over the past two decades;
- The role of universities in Africa in research, evaluation, information transfer and technology development is critical to national social progress and economic growth.

NePAD undertakes to review the current initiatives jointly with UNESCO and other major international donors to ensure that there is a realistic assessment of a nation's potential and constraints militating against its ability to meet international development and educational goals and targets; develop a plan that supports the immediate strengthening of the university system across Africa, including the creation of specialised universities where needed; building on available African teaching staff; establish regional centres of excellence to provide essential research and high level workforce; and establish and strengthen institutes of technology.

AIM OF THE RESEARCH

The research aims to position North-South engineering education collaboration through Conceive-Design-Implement-Operate (CDIO) educational theory, which will ultimately bridge the gap. South Africa is the identified country that will carry much of the burden of leading the reforms in Africa because of the new educational policy reforms, while also ensuring the creation of a CDIO knowledge society on the continent.

METHODOLOGY

Action research was used as the main method. Hence, it allows for small-scale intervention in the functioning of the real world, while also allowing a closer examination of the effects of such intervention. According to Cohen and Manion, action research is situational, collaborative, participatory and self-evaluative [7]. Zuber-Skerrit describes it as a critical and self-critical collaborative enquiry by reflective practitioners who are accountable and make the results of their enquiry public [8]. It is important that practitioners evaluate their practice themselves and engage in participatory problem solving and continuous professional development. The action research team, led by the researcher, comprised the international CDIO Initiative leaders and chosen members, South African leading academics and leaders of the two African satellite centres of the UNESCO International Centre for Engineering Education (UICEE), which cover the North African and East/Central African regions. The plan, therefore, had to develop a strong transfer model of the CDIO educational theory to Africa.

The researcher developed a plan of critically informed action to introduce CDIO in South Africa and Africa through a UNESCO recommendation, with the guidance of the four fundamental aspects of action research, ie plan, act, observe and reflect [9]. The plan took cognisance of the state of engineering education in South Africa and Africa. From the South African perspective, it recognised the efforts taken by the professional body, the Engineering Council of South Africa (ECSA), in aligning accreditation standards to those required by the Washington Accord, which have hugely benefited South African engineering education [10]. However, universities themselves have to carry much of the research and development burden in South Africa. In addition, South Africa has a role to play for the development of the entire African continent.

The CDIO Transfer Model

As the CDIO initiative comprised only North universities as project collaborators, the researcher developed initially a transfer model for the South that would be based on CDIO research centres for the African region, as per the NePAD acknowledgement of the state of African universities, coupled with the advice to develop a single centre of technology excellence for the continent first and then empower the rest. Also, CDIO educational theory would be offered to current practicing engineering educators as a formal academic degree programme at both the Masters and Doctoral levels, who would be able to carry out further research into CDIO to substantiate it as an educational theory [11]. This would be achieved while readjusting current engineering curricula in alignment with the CDIO topical syllabus [12].

The next step was to implement the plan. For South Africa, two leading engineering education academics visited the researcher to evaluate the CDIO initiative for its relevance to South Africa. Very encouraging comments were made by the South African academics that a CDIO-based article be published in South Africa and that a visit by the CDIO team would be welcomed. The researcher published the article to draw the attention of South Africans and the region [13]. Two South

African universities offered to establish a CDIO Centre and a criteria to choose only one had to be developed. For UNESCO, the leaders of the two UICEE satellite centres in Africa were contacted and were well informed about the research. They agreed to set up teams at their centres to work with the researcher on CDIO. The researcher was also invited to make a presentation on CDIO educational theory at the *1st North African Region Seminar on Engineering and Technology Education*, held in Algiers, Algeria, in September 2003 [14]. Both UICEE satellite centres in Africa were represented.

The CDIO Centre Development Plan was designed and sent as an instrument to be completed by the two South African universities, from which only one with the best infrastructure, vision and plans for the expansion of CDIO in its region was to be chosen. The same would apply to the two UICEE satellite centres in Africa. Attached to the plan was a Draft Memorandum of Agreement for discussion.

The observation stage of action research was now in process. The two South African universities returned their responses. The first university pulled out because it would cease existence by 31 December 2003, as it was merging with another neighbouring university, creating a single big university under the New Universities and Technikons Merging Law currently in operation in South Africa. The university indicated that it was, at that time, in no position to enter into any new agreements with any external institutions until the merger process was finalised and that the new institution was going to be a legal entity by the first semester of 2004. However, they confirmed that they would hand over the CDIO processes to the new university management to encourage their part in the new CDIO movement in South Africa in 2004. The other South African university duly completed and returned all the instruments. It should be stated that they demonstrated a very high degree of commitment in developing and promoting CDIO educational theory not only to the rest of the South African universities, industry and other role stakeholders, but to the Southern African region and the African continent.

The *African Centre for Engineering and Technology Education*, the UICEE satellite centre based at the Kigali Institute of Science, Technology and Management, Kigali, Rwanda, indicated they needed more time to consult with the institution's Senate and Council first as the CDIO Centre Development Plan required a high level of commitment. They were then requested to familiarise themselves with the contents of the Memorandum of Agreement and make the necessary comments so that the necessary adjustments to the instrument could be made to suit them, and they confirmed their satisfaction of the contents. They were requested to complete and the Memorandum of Agreement and did so. They also indicated that the CDIO Centre Development Plan would be attended to during the course of 2004. At the time of this research publication, the UICEE North African satellite centre had not responded to the two instruments.

APPOINTMENT OF THE FIRST WORLD CDIO CENTRE

The South African University of Pretoria demonstrated a very high level of understanding of CDIO educational theory and the future direction on the appointment of CDIO Centres. The University's infrastructure, with respect to existing engineering education curriculum and workshops or laboratories, and the fact that the Engineering Council of South Africa (ECSA) accredits all South African universities' engineering education programmes was a huge advantage for them. The University of Pretoria in South Africa was then appointed to become a CDIO Centre for South Africa and the Southern African region and documents were signed at the Massachusetts Institute of Technology (MIT), USA, on 13 November 2003. *This made the University of Pretoria the first CDIO Centre in the world.*

In the researcher's discussions with representatives from the two UICEE satellite centres in Africa during his visit to Algeria for the 1st North African Seminar, he clarified every CDIO Initiative aspect with them with the intent to motivate them to become CDIO Centres for their regions. It was also clarified to them that there is no joining and/or membership fee required.

However, as the CDIO theory of education indicates, an institution has to provide a suitable infrastructure and environment for CDIO systems and products. This means that the engineering education curriculum has to be directly underpinned by workshop/laboratory equipment to enable the teaching, learning and assessment of a CDIO-based syllabus to make an effect. Therefore, this arrangement would be a basic requirement that any institution that aspires to become a CDIO Centre, which has added responsibilities of developing and promoting the CDIO theory to the country and region, is expected to comply with.

The reflection stage of action research was in process now. As the CDIO Centre Development Plan and Memorandum of Agreement were developed for this purpose as a pilot only and had brought so much high quality in the process, the researcher made a recommendation to the International CDIO Council that all future CDIO Centres be appointed on the same basis. This was approved. The Agreement entered into between the CDIO Initiative and other institutions of higher education is completely different from the usual documents that bring two institutions together for the purpose of information sharing and other understanding matters.

There is no fee to be paid by any institution that aspires to join and maintain membership with the CDIO initiative. However, there is some degree of commitment an institution is expected to meet in its part and this may not be too pleasing for some institutions in developing countries, even for those in developed countries. There is a minimum standard or level that a university is expected to function at if it offers higher engineering education with respect to CDIO educational theory requirements; this is the basic requirement of CDIO educational theory. Each higher engineering education institution is expected to and must meet this requirement.

As stated previously, the CDIO Centre model was initially meant for the South only, the researcher reflects that this model has been popular among all CDIO initiative partners that have adopted the expansion of CDIO educational theory worldwide. The MIT and Liverpool University, UK, have made applications to the International CDIO Council to establish CDIO Centres for the North American and Western European regions respectively. These two universities also made use of the instrument initially designed for the South universities, which indicates that all future CDIO Centres have to complete the instrument and submit it for scrutiny. Swedish and Danish universities are also in the process of making a decision about a Northern European CDIO Centre. Also, as the University of Pretoria was initially appointed for the Southern African region

only, it has come to the reality of accepting the task of empowering the entire African continent to ensure that all regions have well resourced centres. Response from the two UICEE satellite centres in Africa is eagerly awaited.

Following the presentation of CDIO educational theory at the 1st North African Seminar, delegates made a recommendation to UNESCO that the CDIO theory of education be adopted as a common engineering education vision for Africa and that the CDIO initiative undertakes this responsibility [15]. It is for this reason that the CDIO Centre at the University of Pretoria should serve Africa to ensure the following:

- CDIO educational theory continues to succeed through further research and development and is should be expanded into all engineering education programmes offered by the Centre's university;
- CDIO should be further expanded to a larger number of South African universities to benefit engineering educators, students, employers and others, as well as benefiting government policies on education generally, and engineering education specifically;
- CDIO is further expanded into the Southern African region and African continent by involving regional and continental engineering institutions and, possibly, governments and other stakeholders;
- Most importantly, as already acknowledged, the CDIO Centre should empower other regional institutions and ensure that minimum engineering education standards are met and maintained by providing CDIO theory-based nationally registered programmes and qualifications;
- The CDIO Centre accredits all CDIO engineering education theory-based programmes in the region and continent;
- The regional Secretariat (staff and offices) is provided to carry out the daily functions of the Centre and coordination of regional activities, such as information dissemination; workshop/seminar/conference and newsletter organisation; provision of a library for research access to CDIO resources and projects; the provision of a CDIO film catalogue on projects, founding and member institutions and individuals; the development and offering of CDIO-based engineering education programmes to the region and continent; and taking the responsibility to promote CDIO membership to other institutions in the region and continent or ensuring that other institutions offering engineering education in the region and continent affiliate to the appointed CDIO Centre;
- Applications be made to UNESCO for *UNESCO Chair* positions for all Heads of CDIO Centres as the programme meets the full requirements. Therefore, it is recommended that a CDIO UNESCO Chair Forum meet occasionally to prepare for the Annual UNESCO UNITWIN Session of UNESCO's General Assembly[16].

RATIONALE FOR THE CHOICE OF UNIVERSITY OF PRETORIA AS THE CDIO CENTRE FOR AFRICA

South Africa has only produced 347 black engineers out of 14,687 engineers registered with the ECSA because of the past racially-based discrimination educational policies. As a step towards rectifying this situation, the national Government launched a national science, mathematics, engineering and technology strategy that has seen the appointment of 102 schools across that will prepare students for higher education in the fields of science, mathematics, engineering and technology [17].

Directly in line with, and support of, the above national goal, the University of Pretoria has launched a Black Engineering Development Programme (BEDP) that aims to address the lack of black engineering academics countrywide by identifying promising young black students and nurturing them to become engineers and academic role models. The University provides a large portion of the required overheads and facilities to implement the project. The BEDP seeks to identify annually at least 100 or more gifted and promising young students for a five-year Bachelors degree engineering study period. A total of 25% will be supported to continue towards a Masters degree, and 10% of them towards a Doctoral degree. Upon completion of a doctorate, they will be offered positions in the University's Faculty of Engineering [18].

The University of Pretoria launched the Automotive Industry Development Centre that, through its research and development activities, by the period between September 2001 and September 2002 had increased the South African annual vehicle exports by 37% and increased South Africa's market share from 0.61% to 0.73%. At a time when the world motor vehicle production slumped by 3.9%, the South Africa's motor vehicle production increased by 13.9%. In a bid to support the Black Economic Empowerment strategy through intensifying manufacturing and production industrialisation, it committed itself to the Joint Supplier Council (a body that represents seven of the country's leading manufacturers) to make sure that by 2012, 30% of the local automotive components manufacturing industry would be in black hands [19].

In addition, the CDIO educational theory requires a world-class South university that will work directly with the North while carrying the burden to uplift other poorly equipped South universities. The University of Pretoria was one of the few universities to comply with this requirement. No other university has made such commitments to improve historically disadvantaged communities in the country so far. They have also committed themselves to advancing Africa's engineering education.

CDIO AS A PHILOSOPHY OR THEORY TO TRANSFORM ENGINEERING EDUCATION

The development and reconstruction of philosophy, education and social ideals and methods go hand in hand. Whenever there is a special need for the reconstruction of education at any given time, it is because of changes demanded in social life that accompany the advancement of science, the industrial revolution and the development of democracy. Such practical changes always demand educational reformation to meet them and few bold people lead the process by asking what ideas and ideals are implicit in these social changes, and what revisions they require of ideas and ideals that are inherited from older cultures. When a social system affects or becomes influential to communities, its connection with a conflict of interests calling for a programme of social adjustment may always be discovered, and this is where the intimate connection between philosophy and education emerges.

However, it should be remembered that European philosophy originated under the direct pressure of educational questions. Education offers an advantage to penetrate human beings as distinct from the technical significance of philosophical discussions. The educational point of view enables one to envisage philosophic problems when they arise, and where acceptance or rejection makes a difference in practice. If

education is agreed to as the process of forming fundamental dispositions, intellectually and emotionally towards nature and other fellow citizens, then philosophy may even be described as the general theory of education. Education is the laboratory in which philosophic distinctions become concrete and are tested. Philosophy is the theory of education as a deliberately conducted practice. It is fundamental in connecting philosophy with thinking in its distinction from knowledge. Knowledge, with specific reference to grounded knowledge, is science and represents objects that have been settled, ordered and disposed of rationally, while thinking is prospective in reference. Thinking is occasioned by an unsettlement and aims at overcoming a disturbance.

Philosophy is thinking what the known demands of us and what responsive attitude it exacts. Philosophy is an idea of what is possible and not a record of accomplished facts; hence, it is hypothetical like all thinking. It presents an assignment of something to be done or something to be tried. Its value lies not in furnishing solutions but in defining difficulties and suggesting methods to deal with them. Philosophy is thinking that has become conscious of itself and which has generalised its place, function and value in experience.

Dewey argues that philosophy is generally defined in ways that imply a certain totality, generality and ultimateness of both subject matter and method [20]. With respect to subject matter, philosophy is an attempt to comprehend and totality means continuity, thus carrying on of a former habit of action with the necessary re-adaptation to keep it alive and growing. The generality and ultimateness of philosophy implies the disposition to penetrate to deeper levels of meaning.

The wholeness characteristic of philosophy is a power to learn or to extract meaning from even the unpleasant vicissitudes of experience and to embody what is learned with the ability to go on learning. The philosophic attitude is general in the sense that it is averse to taking anything as isolated and it tries to place an act in its context, an indication that constitutes its significance. An individual who is open-minded and sensitive to new perceptions and who has concentration and responsibility in connecting them has a philosophic disposition. One of the popular characteristics of such a person is the demonstration of calmness and endurance in the face of difficulty and loss and the power to bear pain without complaint. This is specifically attributed to the Stoic philosophy and not general philosophy.

Philosophy's two fundamental functions are to criticise existing aims with respect to the existing state of science, pointing out those values that have become obsolete with the command of new resources. This shows what values are merely sentimental because there are no means for their realisation, and to interpret the results of specialised science in their bearing on future social endeavour.

THE CONSCIOUS INFLUENCE OF THE CDIO LEARNING ENVIRONMENT

The CDIO learning environment is deliberately regulated in order to produce a very high degree of its education effects, as Dewey also agrees that an intelligent home differs from an unintelligent one chiefly in that the habits of life and intercourse that prevail are chosen, or at least coloured, by the thought of their bearing upon the growth and development of young ones. The CDIO learning environment forms the mental and emotional disposition of behaviour in students by engaging them in activities that arouse and strengthen certain purposes and entail consequences. This arrangement continues to strengthen the primary general functions of education on a child, which are as follows:

- To direct in a certain continuous course, instead of dispersing aimlessly by regulations and rules;
- To control, which only means an emphatic form of direction of powers and covers the regulations or rules gained by a child through his/her own efforts, quite as much as those brought about when others take the lead;
- To guide, which conveys, at best, the idea of assisting through cooperation the natural capacities of individuals.

The deliberately designed CDIO learning environment directly complements the education given by parents to their children. Parents strive hard in taking the responsibility of shaping their children's manners and morals, even by going to the extent of providing educational environments in their homes. The CDIO learning environment complements this and results in the total education of children. Therefore, the aims of parents, students, CDIO engineering educators, employers and other beneficiaries of the system are fulfilled. The conscious influence that a CDIO learning environment has on students creates a wider and more balanced environment by which students would likely to be influenced, even when left to themselves. The atmosphere surrounding students creates a spirit that is the chief agent in forming manners, and manners are minor morals. This environment assures students of an educative, harmonious surrounding of form and colour that results in a standard of good taste and aesthetic appreciation.

Through its teamwork approaches, it also makes an individual a sharer or partner in the group activity so that each individual feels success as he/she is possessed by the emotional attitude of the group he/she interacts with; the group's failure are then perceived as his/her failure too.

As soon as the individual is possessed by the emotional attitude of the group, he/she is alerted to recognising the special ends to which the group aims, and the means employed to secure success. The individual's beliefs and ideas take the form similar to those of others in the group, while also achieving pretty much the same stock of knowledge, since that knowledge is an ingredient of his/her habitual pursuits. Within the team that students work, there is a variety of skills needed for the success of a project. These skills include the ability to cooperate, plan, write documents and communication, and, when put together, creates a spirit of project organisation that leads to a commitment to development, thus extending itself to matters of social development commitments.

A careful inspection of CDIO learning theory has revealed that it has linked those teaching methods that have always been permanently successful in formal education. It has been revealed that its efficiency depends on the fact that it goes back to the type of situation that causes reflection out of school in ordinary life. It gives students something to do and not something to learn, and the doing is of such a nature as to demand thinking or the intentional noting of connections. Consequently, learning becomes the natural outcome. The nature of the CDIO learning environment is one that arouses thinking and, of course, suggests something to do that is neither routine, nor capricious, and yet sufficiently connected with

existing habits to engender an effective response. Where students are engaged in doing things, it has been found – even with comparatively indifferent modes of instruction – that students' inquiries are spontaneous and numerous. Furthermore, the proposals for solutions are always advanced, varied and ingenious.

CONCLUSION

Some members from developing countries might view the requirements for joining the CDIO initiaitve as criteria to keep higher education institutions of developing countries away from participating as equal partners with institutions from industrialised nations. That way of thinking would be grossly incorrect. If the infrastructure of an institution is not able to provide for the CDIO learning environment, then CDIO educational theory will not be a success at that particular institution.

The NePAD is emphatic on the participation of, and collaboration between, developed and developing countries on an equal partnership basis. This should not mislead people into thinking that this equal partnership participation will just happen. For equal partnership participation and collaboration to successfully occur between developed or industrialised nations and developing countries requires a minimum level of common understanding based on the available resources of both sides.

In South Africa, any university that would like to offer, or currently offers, any engineering education programme is inspected first by the ECSA to ensure that it has the required state of the art equipped workshops or laboratories and suitably qualified staff. When the requirements are met, it is accredited to offer the engineering programme for a specific period of time, after which it is inspected again to ascertain that it keeps its facilities up-to-date.

As stated earlier, ECSA is a member of the Washington Accord and the International Mobility Register of Engineers enables South African engineering graduates to be recognised by the world's greatest industrialised nations; this level of international recognition was not achieved by South Africa without some pain. It should be noted that the founding signatories of the above international bodies comprise Australia, Canada, Hong Kong, Ireland, New Zealand, the UK and the USA, while Japan and FEANI hold provisional membership. South Africa's signatory status was achieved in 1993 and full membership was granted in 2000 after seven years of thorough inspection and scrutiny of the infrastructure and compliance with the accreditation procedures of the Accord by the individual founder members.

It is for this reason that the researcher is in full agreement and support of the decision that the CDIO initiative took in developing the CDIO Centre Development Plan and in making institutions commit themselves to become Regional CDIO Centres. This enables universities to function at almost the same standards as industrialised nations' universities. This will enable the existing engineering education gap that currently exists between North and South to be gradually bridged.

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