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The international trends and reforms in engineering education at King Abdulaziz University

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ABSTRACT: In this article, the authors provide a conceptual framework of reforms in engineering education at King Abdulaziz University (KAAU) in Jeddah, Saudi Arabia. They highlight the various global trends and essential educational elements pertinent to reforms in engineering education, which are being drawn up and adopted by various leading international organisations in the field of engineering, eg FEANI, Engineering Council (UK), ABET and the UICEE. As a case, the authors outline the various phases of reforms and precepts adopted for curriculum development by the Faculty of Engineering at the KAAU over the past 30 years or so. The aspect of curriculum development is specifically focused on in order to shed light on how the globalisation trends and Saudi Arabia's socio-cultural and industrialisation requirements are blended in its engineering education.

INTRODUCTION

The world is changing in fundamental ways and engineering education must be responsive to these changes [1]. The increased level of internationalisation of engineering education has provided academic institutions with new opportunities for further cooperation in regional/global networks for engineering education [2]. This change is pervasive and includes the application of mathematics beyond elementary calculus, with a primary emphasis on design codes and teamwork skills to address engineering problems typical of the current fast-paced quality-oriented industrial environment. Therefore, engineering education courses that are aimed only at the fulfilment of the actual practical requirements of various industries are now regarded as short-sighted, since such courses are no longer appropriate to the long-term needs of a rapidly changing society. Modern engineering courses are targeted at developing students' higher-order or metacognitive skills, problem-solving, active learning, information technology and communication skills so that the knowledge gained can then be adapted and applied to a given problem, or a set of problems, in the practical situation [3]. Faced with a changing world and the need to change to compete, or even to keep up, the engineering curriculum planners have a formidable task in view of the constraints of time, money and culture. The most important additional constraint is the need to put in place a new dynamic system to replace the old static system [1].

Curriculum development is one of the most important challenging tasks. It provides directions and milestones along the way to the achievement of goals and missions for any programme. It is a dynamic activity that has to encounter various national and international constraints related to local market requirements, global engineering educational trends, socio-cultural aspirations of the society, professional skills and knowledge content. The curriculum development process has to be alive and responsive to the profound changes taking place in the engineering practice driven by fast developing information technology, intense global competition in both manufacturing and services, and the imperatives of environmental protection and sustainable growth [3].

It is not surprising to find that the need for change is not just an outside feeling and practice; but, as a matter of fact, it has been a continual activity undertaken by the Faculty of Engineering at King Abdulaziz University (KAAU), Jeddah, Saudi Arabia [4]. In this article, the authors highlight the global trends pertinent to reforms in engineering education adopted by various leading international organisations, pedagogical issues/principles in engineering curriculum and the various phases of curricular reforms undertaken by the Faculty of Engineering at the KAAU since its inception in 1974, in view of globalisation trends and the local parameters of fast socio-economic developments. The main engineering programmes at the KAAU, as well as its goals, are also presented here.

ENGINEERING PROGRAMMES AT KING ABDULAZIZ UNIVERSITY

King Abdulaziz University, located in the western region of Saudi Arabia, was established in 1387H (1967) as a private university after visualising the need for higher education in the region. It was declared by a Royal Decree as a state university in 1391H (1971). Over three decades, the University has become an eminent institution of higher education that responds to the changing educational requirements of the society. It now has an enrolment of about 42,000 students, with over 5,000 faculty members and staff. It has nine faculties that cater for diverse human resource development programmes [5].

The Faculty of Engineering was established in 1394H (1974). There are currently 179 faculty members and 199 graduate and 2,303 undergraduate students. There are nine departments and 12 programmes offering the Bachelor of Science (BSc) degree in engineering. A number of departments also offer graduate programmes leading to Master's and PhD degrees [5]. The departments and programmes are as follows:

- Civil Engineering;
- Thermal Engineering & Desalination Technology;
- Production Engineering & Mechanical System Design;
- Aeronautical Engineering;
- Industrial Engineering;
- Nuclear Engineering;
- Chemical & Materials Engineering;
- Mining Engineering;
- Electrical & Computer Engineering:
  - Computer Engineering & Control;
  - Power & Machine Engineering;
  - Electronics & Communication;
  - Biomedical Engineering.

The goals of engineering education at the KAAU are as follows:

- To equip students with a basic knowledge of science, engineering and social science subjects;
- To develop students' ability in analytical and creative thought and broaden the scope of understanding for engineering disciplines at large;
- To prepare qualified engineers and enhance their proficiency to undertake future engineering responsibilities with a thorough understanding of the effective role they are expected to play in Saudi Arabia's national development plans;
- To create postgraduate programmes (for MSc and PhD degrees) in various departments for qualified students;
- To emphasise the significance of scientific research and community services, and encourage academic staff and graduate students to conduct research activities and publish scientific articles in reputable professional journals;
- To organise conferences, symposia, short courses and workshops with a view to raising the standards of engineering education, as well as enhancing professional interactions;
- To realise the importance of continuous updating and development of engineering curricula to match the accelerated development in all applicable areas;
- To provide practical orientation for challenging careers in various engineering fields [6].

THE INTERNATIONAL SCENARIO OF REFORMS IN ENGINEERING EDUCATION

Engineering is a truly global profession, with multinational and transnational corporations employing engineers around the world. In response to the needs of the engineering community, a number of international bodies have been established to address the issues of quality assurance outside their own territory through consultations, programme evaluations and mutual recognition agreements. These are presented below.

FEANI

Bodies like the Federation Europeanne d'Associations Nationales d'Ingenieurs (FEANI) have initiated and participated in the process of upgrading engineering education in Europe. The preamble to the FEANI states that an engineer today must have effective interpersonal skills, be conversant in new technologies and their place in society, and have the ability to anticipate the future workplace requirements and prepare himself/herself accordingly [7]. This renewal of emphasis stems, in part, from the social and political fallout due to events related to higher education in general. Engineering education, in particular, has to respond to recommendations and demands from industry to change the way in which engineers are educated, especially in view of new international trade agreements, such as those occurring within the European Economic Community (EEC), the North American Free Trade Agreement (NAFTA) and, lately, the World Trade Organization (WTO). Programmes are reviewed and future policies on engineering education developments and challenges to engineering professions are given. The changes recommended by many in industry, academia and government revolve around the perceived present and future needs of industry and society. Recommendations largely relate to the perceived practice of engineering in the 21st Century.

Also, the standards and procedures for Eur Ing (Europeanne Ingenieurs) registration have been prepared and described together with their recently approved status by the European Community. Since the inauguration of the title in 1987, there are now some 17,000 registrants across 22 countries of the FEANI. The Eur Ing's requirements of a seven-year package of education, training and experience have successfully bridged the differing formation systems of the FEANI countries. Also, the increasing use of the title has assisted the standing and mobility of engineers within Europe [8].

Furthermore, there are institutions or bodies whose main job is to evaluate, assess or accredit engineering education. They go out by request to determine the substantial equivalency, or at least give a sense of minimum standards for institutions. The following three major engineering professional organisations are reputable worldwide: the UK-based Engineering Council, the US-based Accreditation Board for Engineering and Technology (ABET) and the UNESCO International Centre for Engineering Education (UICEE) at Monash University, Melbourne, Australia.

Engineering Council (UK)

The Engineering Council (EC) is greatly concerned with the academic and professional standards of those entering the engineering profession and with the continuing professional development (CPD) of those already in professional practice. The Council is an organisation based on the work of an earlier group, the Council of Engineering Institutions (CEI). These bodies effectively formalised dialogue among all the engineering institutions incorporated by Royal Charter. The EC is charged with certain responsibilities for the engineering profession, such as the regulation of standards, including educational standards. The collaboration of member institutions led to an agreement and confirmation on *Standards and Routes to Recognition* [9]. This document defined the criteria for full membership and the Chartered Engineer (CEng) status, including the minimum academic qualifications required for a bachelor's degree with honours in an appropriate subject [10]. Further to demands from engineering employers, the EC and engineers have led the way to all willingly accepting the claim that future engineering programmes must teach undergraduates how to manage career changes, advances in technology, and pursue their own continuing professional development. Emphasis is placed on the need to integrate the process skills or key skills of communication (speaking, writing and presentation), working with others, and managing lifetime learning and development into the curriculum.

The ABET

The USA has no centralised entity managing higher education or promulgating higher education policy. Accreditation is one means of ensuring that minimal educational standards have been met. In the USA, accreditation is non-governmental and is voluntary on the part of the institution or programme(s) being evaluated. Accreditation standards for engineering have been adopted by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET), a federation of 28 participating societies that represent the engineering and engineering-oriented disciplines, and virtually all engineering subjects in the USA. The evaluation begins with an institution and its degree programmes. Each programme in every institution prepares a self-study report that is examined closely by the ABET as part of the accreditation process. The ABET currently accredits over 1,500 engineering programmes, 700 engineering technology programmes and 50 programmes in engineering-related areas, such as occupational safety, industrial hygiene and surveying. Thus, with the input and guidance of industry and academia, the ABET sought to develop an accreditation system that would provide the means for engineering programmes to successfully prepare graduates for engineering practice in the 21st Century [11]. The ABET is actively involved in assessing engineering programmes throughout the USA on a consultative basis, with the objective of indicating to the US university how well its programmes meet the criteria used for the accreditation of similar programmes. The ABET has been active in working with other nations to recognise equivalent accreditation systems and to help many countries set up their own accreditation system.

One further step in this regard was taken in 1988, when the Washington Accord was adopted by a mutual agreement among six different countries (Australia, Canada, Ireland, New Zealand, the UK and USA), especially with regard to the civil engineering discipline. This agreement stipulates that each country recognises the accreditation system of the others as being substantially equivalent so that graduates of an accredited programme from any of the six countries involved would be considered to have the equivalent educational experience of any other accredited programme. The ABET feels strongly that the US system can be used as a model for other countries and that each country should adopt an accreditation system that meets its own needs. The engineering educational system should respond to the high priorities of the country, and not just emulate that existing in another country [12].

The UICEE

The UNESCO International Centre for Engineering Education (UICEE), the world's first centre for engineering education established on the recommendation of the UNESCO Steering Committee on Human Resource Development for Technical Industry Stimulation, is located in the Faculty of Engineering at Monash University, Melbourne, Australia. The UICEE adds a new dimension to the process of internationalisation of engineering education. It is a unique development that has been endorsed by a number of academic institutions and professional organisations. The mission of the UICEE is to serve the world's engineering community, with a particular commitment to the transfer of expertise from the developed to the developing countries. Its main objectives are to facilitate the exchange of expertise and research on engineering education, and to act as a national and international clearinghouse for information on textbooks, engineering teaching courseware, software and equipment. The Centre's paramount objective is to access, evaluate and disseminate information, and to ensure an active transfer of information on engineering education between the developed and developing countries, considered essential for the development of the developing world and which is so vital to world peace, stability and progress [13].

PEDAGOGICAL ISSUES/PRINCIPLES IN ENGINEERING CURRICULUM

As stated earlier, the world is changing in fundamental ways and engineering education must be responsive to these changes. While basic science and engineering principles, knowledge and skills still need to be acquired, the new pedagogical issues/principles that affect the system for the underlying expertise must be in tune with the times. Major pedagogical issues/principles of global significance that need to be considered for curricular reforms are described below [1].

Holistic Education: For the engineer of the 21st Century to be able to cope with the global changes taking place in the world that revolve around the perceived present and future needs of industry and society, engineering education must become more holistic. From 1960 to 1985, engineering education was based on an analytical (science) model. The future engineering education must be more integrative. Table 1 provides a contrast of the two approaches, with emphasis on holistic engineering education [14].

Table 1: Components of the holistic engineering education of the 21st Century.

Analytic (Science) Model, 1960-1985	Integrative Model, 2000 and Onwards
Vertical (in-depth) thinking Abstract learning Reductionism-fractionation Understand certainty Analysis Research Solve problems Develop ideas Interdependence Technological-scientific base Engineering science	Lateral (functional) thinking Experimental learning Integration-connecting the parts Correlate chaos; handle ambiguity Synthesis Design/process/manufacture Formulate problems Implement ideas Teamwork Societal context/ethics Functional core of engineering

Theories of Teaching and Learning in Engineering: The literature indicates that teaching and learning in engineering must be a cognitive apprenticeship-based approach, which is underpinned by the following theories of learning: algo-heuristic theory; landamatic theory of learning based on the snowball method; constructivism; and Bloom's taxonomy of educational objectives [2].

Algo-heuristic Theory: Engineers must demonstrate the acquisition of engineering knowledge by using research skills, problem identification and solving skills, critically evaluating information and transferring knowledge to new situations, as well as making responsible decisions, thus developing attitudes, beliefs and values [2].

Landamatic Theory: This theory of learning emphasises teaching students cognitive operations, algorithms and heuristics, which make up general methods of thinking (ie intelligence). Using this model, instructional designers break a complex task into components, including the ambiguous and unobservable cognitive processes. Landamatic instruction involves the *snowball method* whereby the multiple steps in a process are taught singly, but always as an addition to prior steps. Through practice and application, all of the steps in the process eventually become automatic, and lead to an expert level of performance. The key to this model is teaching students how to discover these processes independently, so that they are able to apply algo-heuristics to original situations [15].

Constructivist Theory: Constructivism is an approach to teaching based on research about how people learn. Many researchers claim that each individual *constructs* knowledge, rather than receiving it from others. Constructivist teaching is based on the belief that students learn best when they gain knowledge through exploration and active learning. Hands-on materials are utilised instead of textbooks, and students are encouraged to think and explain their reasoning instead of memorising and reciting facts. Education is centred on themes and concepts, and the connections between them, rather than isolated information [16].

Bloom's Taxonomy: Bloom suggested that educational objectives can be classified hierarchically within three major domains, namely the cognitive domain, which is concerned with knowledge and its use; the affective domain, which is concerned with emotional responses and values that are taught; and the psychomotor domain, which is concerned with physical and manipulative skills. Bloom's taxonomy of educational objectives has had a major influence upon curriculum development [17].

Design: The best preparation for handling any change has been perceived as teaching students design, even if they are not engineering students. Students should learn the processes of problem clarification, the use of information flows, the identification of stakeholders, the creation of product design and development teams, the creative process of generating options, the weighing of tradeoffs in technology assessment and the development and testing of prototypes. The teaching of design itself has recently seen the emergence of a common approach for the first time [1].

Active Learning: The skills on the job and the information required to do the job are changing far more rapidly than before. To prevent skill obsolescence and to handle change, students must learn *how to learn*.

Collaboration: Engineers work in teams and they must be prepared to best handle teamwork dynamics. Active learning and teamwork will provide experiences in collaboration. Diverse teams can be more creative and work better in the global economy. To make teams work well, the learning of conflict resolution skills, such as negotiation, mediation and cross-cultural awareness, is significant. Collaboration further involves the development of foreign language skills and acquiring international experiences to aid working with people from other countries and cultures.

Interdisciplinarity: Another pedagogy is Problem-Based Learning (PBL), which requires and promotes interdisciplinarity. In engineering education, it is also called project- or product-based learning. Research shows that on measures of complex interdisciplinary thinking, which more accurately represent professional behaviour, students who have PBL experiences do better than those in traditional curricula. [1] Therefore, more time needs to be spent teaching interdisciplinary subjects like project management in engineering education. Also, inter-disciplinarity must include global learning from international standards to cultures and industry practices in other countries.

Information Technology Skills: It has been recognised that the rapidly evolving technologies of the 1990s will put the technical updating of professional engineers at a premium for employers who wish to remain competitive and for employees who wish to remain competent. Engineering students must learn the latest in information technology because the flow of information defines the life and the health of the workplace, from the self-employed to multinational corporations. It also allows for virtual teams with members from different locations and even different countries. With well-spaced, global participation, a project team can work continuously in either education or industry [1].

ENGINEERING EDUCATION AT KING ABDULAZIZ UNIVERSITY: PHASES OF REFORMS

Curriculum reforms and development at the KAAU are initiated by standing committees on curriculum within all departments. All Faculty members are obliged to participate in the process according to their fields of specialisation. At the Faculty level, the Faculty Council debates the changes and brings it into conformity with other departments of the Faculty. Finally, the University Council approves the curriculum development plans. Since the inception of the Faculty of Engineering in 1974, the curricula have been thoroughly revised three times. The salient features of the changes made, along with the imperatives of changes, are presented below.

First Curriculum

Engineering education at the KAAU was introduced in 1975. The objectives of the Faculty of Engineering covered educational, research and community service activities. The initial curricular objectives included the following:

- To provide students with basic knowledge in basic sciences, humanities and engineering;
- To develop students' abilities in analytical and engineering skills and innovations;
- To consolidate ethical and Islamic values;
- To facilitate students qualifying to participate effectively in delineation and engineering solutions related to the development plans of the Kingdom of Saudi Arabia [18].

The courses were of fundamental nature with a minimum of specialisation in separate branches. There was a thorough training in the basic sciences, as well as in engineering, with 145 units required for graduation. Of this, 93 units were allocated to a broad spectrum of basic sciences, engineering sciences and humanities, compared with only 52 units allocated for specialisation. The general type of engineering curriculum was considered suitable because of the strong demand for engineers in Saudi Arabia at that time; very few Saudi engineers were available, whereas the national development was proceeding at a very fast pace. In general, the curriculum was designed to respond to these objectives.

Second Curriculum

The engineering curriculum at the KAAU was revised and implemented in 1987. Graduates and employers were solicited to respond to a questionnaire and give their feedback on the first curriculum. Many graduates pointed to the need for more training in design. Employers pointed to the need for more technical/practical orientation of the curriculum. Based on the feedback from graduates and employers, most of the Faculty members concluded that there was a need for more emphasis on specialisation.

After prolonged deliberations, the graduation requirement was increased from 145 credit hours to 165 credit hours. The share of the Faculty courses became 91 units and the departmental specialised courses increased to 74 units (compared with 52 units in the first curriculum). A significant number of units was allocated to computer-based courses [4].

New Curriculum

In view of the emerging international trends and pedagogical principles pertinent to engineering curriculum, engineering education at the KAAU is undergoing a revision once again. In keeping with the global trends and local requirements, observations and inputs from employers, graduates and faculty members were collected, in the light of which changes have been made. Thus, the goals of the new curriculum to be translated in terms of qualities of engineering graduates have been drawn up afresh and are enumerated as follows:

- Graduates should have advanced bilingual communication skills (in English and Arabic languages);
- Graduates should be well equipped with basic knowledge in fundamental sciences, engineering and humanities and should have the ability to exercise analytical and innovative judgement during their professional careers with particular emphasis on narrow specialisation;
- Graduates should be able to utilise modern technical facilities, for example, computers and the Internet and to apply such facilities to engineering work;
- Graduates should be well prepared for teamwork;
- Graduates should observe ethics in the engineering profession in accordance with Islamic traditions;
- Graduates should be aware of environmental problems and should know how to deal with them;
- Graduates should be well prepared for leadership;
- Graduates should have the proper sense of responsibility towards their society and country;
- Graduates should be able to develop their intellects and update their knowledge to remain abreast of modern technological developments.

From 1996, the Faculty of Engineering has also been working to acquire substantial equivalency for its nine engineering degree programmes through the ABET. *Substantial equivalency* implies that Faculty graduates possess the competences needed to begin professional practice at the entry level, at par with those of US universities [19]. This will ensure international credibility of KAAU engineering programmes and usher in many intangible benefits for Faculty graduates and Faculty members in the long run [20]. Apart from the other elaborate documentations required for this process, a comparative analysis of the existing programmes was undertaken. The tentative results of this exercise are presented in Table 2.

Table 2: Tentative results of the three methodologies of curriculum (showing credit units).

	Second Curriculum (1987-2001)	New Curriculum	ABET Criteria
Mathematics & Basic Science	32	36	32
Engineering Science	83	55	32
Engineering Design	16	20	16
Humanities & Social Science	16	24	16
Other skills, etc	18	20	---

COMPARISON OF NEW ENGINEERING CURRICULUM WITH ABET CRITERIA

In the light of long deliberations held among faculty members at various levels and the relevant inputs and comments provided by external bodies, it is certain that the new curriculum will make up for deficiencies, as well as effectively meet the global challenges of the present times. It is obvious from the contents of Table 2 that the existing programme is well above the minimum credit unit criteria set by the ABET. The courses offered in *Other skills, etc* are desirable and are a plus for the programme. The major discrepancies lie in basic and engineering science credit units for the present and new curricula, and are due to the new definitions assigned to them [20][21]. The present curriculum revision is based on the desired attributes of engineering graduates for the 21st Century. Graduates should be technically competent, critical and creative thinkers, life-long learners, effective communicators, team players and globally aware. They should understand process and systems design and integration, display high ethical standards, appreciate the social context of engineering and industry-business practices, and have a positive attitude towards life.

Furthermore, in keeping with the current international trends in engineering education and the need to incorporate the pertinent pedagogical issues/principles in engineering curriculum discussed above, plus satisfy the requirements of the ABET Engineering Criteria 2000, the Faculty of Engineering (KAAU) has added two new courses to the core curriculum. The courses are Introduction to *Engineering Design I* (2 credits) and *Introduction to Engineering Design II* (3 credits). The two courses will be taught over a period of two semesters and will include topics like the engineering design process (how engineers approach and solve problems); computer modelling of processes and products; quality principles; teamwork skills; metacognitive learning skills (such as self-regulation in learning, time management, learning new materials, setting goals, etc); communication skills in English; presentation, organisation and assessment of technical work; and preparation of both short and elaborate/lengthy technical reports.

FURTHER DEVELOPMENT STRATEGY

The strategic plan of the Faculty of Engineering is part of the University's global five-year plan (2000-2005), which is part of the National Five-Year Development Plan for the same period. [5]. The maintenance of excellence in the student body, faculty, and educational and research programmes continues to be the highest goal of the University. Consistent with its goals, the KAAU strives hard to achieve excellence in its academic programmes and meet superior international standards. This objective has immensely affected all aspects of its policies including the recruitment of staff of a high calibre, design of programmes to meet those standards set by various international organisations, like the ABET and UICEE, and providing adequate academic and support facilities for engineering education. An adequate internal and external funding bolsters continuous support for research related to Saudi Arabia's technical/engineering needs. The availability of equipped laboratories with highly qualified technicians, as well as the support facilities in the library and computer services, is always an important consideration. During the last few years, the Faculty of Engineering has successfully augmented the number and scope of personal computer (PC) laboratories for use in teaching.

Faculty teaching performance and advising skills have been the major concern of the Faculty of Engineering for the past few years. New faculty members are prepared for teaching by way of orientation workshops. Teaching quality for all faculty members is continuously enhanced and developed through short courses and workshops delivered by international professionals invited through the University's Center for Teaching & Learning Development [5]. Excellent support is provided by the University's Central Library and Central Computer Center. In addition, the Faculty of Engineering has its own library facilities that adequately meet the requirements of both its faculty and students. Easy access to the Internet and e-mail system facilitates research and academic exchange for faculty and students. Extensive computing power and an instant communication network is at hand, which is being developed in line with modern trends in education.

Thus, the curricular revisions and improvement measures adopted to date have largely enhanced the development of engineering education at the KAAU. The Faculty is firmly committed to a process of continuous professional development. Along with the dissemination of knowledge, the role of research is being emphasised during the promotion of faculty members. Consequently, a research culture is emerging among Faculty members and graduate students. Future plans include high priority being given to the development of postgraduate education and interdisciplinary research.

CONCLUSIONS

In searching for a conceptual framework for reforms in engineering education at the KAAU, the authors carefully examine international reform trends in engineering education and discuss the various phases of curricular reforms implemented in engineering education at the KAAU. Curricular goals and reform activity at the KAAU that have helped its graduates become cognisant of national and international trends and to be best prepared as engineers of the 21st Century are also highlight. It is rewarding to find that the activities of the Faculty of Engineering in reforming its curriculum satisfy the ABET's accreditation criteria, especially after the specific deficiencies or weaknesses noted by the EAC were solved. All the engineering programmes offered by the Faculty have been approved to be substantially equivalent to ABET criteria.

The ultimate goal of the Faculty of Engineering is to facilitate the acquisition of the knowledge, skills and strategies needed to professionally train future engineers. Current trends are such that engineers of the 21st Century are now expected not only to be efficient in their technical fields, but also have leadership qualities, good knowledge of contemporary issues, ability to think critically, sensitivity to ethical responsibility, skills to communicate effectively, and the ability to engage in life-long learning and cultural literacy.

Finally, the authors emphasise that curricular reforms in engineering cannot be a one-time thing; rather, it must be an ongoing process aimed at achieving continuous improvement in engineering education. The Faculty of Engineering should continue to strive for higher standards providing a steady stream of efficient engineers, absorbing new paradigms of engineering practices, consolidating its existing programmes and spearheading the vertical and horizontal development of engineering education in Saudi Arabia.

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