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Developing a computer engineering undergraduate curriculum: the challenges and solutions

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ABSTRACT: Developing a computer engineering (CE) undergraduate curriculum is a difficult task that involves many challenges, such as continuous advances in technologies, accreditation, professional standards, local and international market requirements, student intake background, and institutional objectives and resources. In this article, the authors explain in detail the challenges encountered and the solutions adopted to come up with a balanced curriculum, which satisfies all the stakeholders of the programme, and at the same time meets national and international accreditation. This experience was gained while developing a CE curriculum at the University of Bahrain (UOB). The greatest challenge is the mismatch of the international standards for curricula, which are aligned with the international market, and the local market in developing countries, where there is a lack of a computer manufacturing industry. The authors propose a comprehensive framework for CE curriculum development to be used as a systematic guide, especially for universities with similar circumstances to the UOB.

Keywords: ABET, accreditation, computer engineering, engineering curriculum, IEEE standards, industry demand

INTRODUCTION

Computer engineering (CE) is the discipline that integrates electronics engineering and computer science. In the era of rapid technological advances, CE has its own discipline identity with expanding areas of specialty. Computer engineering education consists of applying the theories and principles of computing, mathematics, science and engineering to design hardware, software, networks, and processes to solve problems and to build applications.

The Association for Computer Machinery (ACM) and the Institute of Electrical and Electronic Engineers (IEEE) in creating, and then revising, the standard for CE curricula helped to define the CE major in education [1]. The ACM/IEEE review task force issued in 2004 and 2016 [2] comprehensive reports that explain in detail all aspects related to the discipline, its background and evolution, the CE curriculum body of knowledge and other curriculum implementation issues.

There are many challenges facing CE curriculum development; the programme should satisfy the requirements of the educational institution, national and international accreditation bodies, as well as international professional standards and be comparable to reputable international universities. In addition, graduates from the programme should be competitive engineers for the local job market, which might differ from the international one. For instance, the computer industry may not exist in a developing country. Therefore, there may be a mismatch between the curricula offered by CE programmes and the actual needs of such communities. This problem was identified by Aldamour and a solution was proposed to structure the curriculum in dual successive funnels rather than the traditional single funnel model, and to introduce technology-wide areas called technology expansion areas [3]. In the proposed model, students develop their professional skills, such as to better integrate with the work environment of a developing country.

In the literature a number of recommendations for designing curricula are discussed. For instance, Cico et al emphasise organising the curriculum material in modules and classifying it into three levels: introductory; intermediate; and advanced, in addition to teaching cutting-edge technologies and new research topics in the final year to make students agents of technology change in industry and public entities [4].

In their paper, Erdil and Bilsel concluded that an engineering curriculum must be broad in order to provide diversity and depth of skills [5]. In developing countries, the marketplace forces the production of practical engineering courses because of the needs of the marketplace. This is in contrast to developed countries, where there is a general engineering education and on-the-job training. So for developing countries there was a reduction of humanities and social sciences courses. Further curriculum design worth mentioning may be found elsewhere [6-8].

Reported in this article is the experience learnt, while developing the CE curriculum at the University of Bahrain (UOB). The market in Bahrain applies information technology and computer services in support of computer-based industry comprising telecommunication companies, petroleum companies, an aluminium factory, banks and other business enterprises [9]. At the UOB, the CE programme is offered in the CE department, which is in the College of Information Technology, with computer science and information systems.

The last update of the CE curriculum was in 2010. The main objective for updating the curriculum was to design a cutting-edge curriculum that copes with new technologies and trends, as well as preparing graduates for the local and international IT and engineering workplace. The development of the CE curriculum is challenging; hence, the objective of this article is to demonstrate all the challenges encountered and the ways to overcome them, and therefore develop a framework for CE curriculum design or update.

ACCREDITATION

The CE programme in UOB was accredited by the Accreditation Board of Engineering and Technology Inc. (ABET) - which mainly operates in the USA - in 2010 and 2014 under the Engineering Accreditation Commission (EAC) of ABET [10]. The Accreditation Board of Engineering and Technology Inc. has eight criteria for engineering programmes: students; programme educational objectives; student outcomes; continuous improvement; curriculum; faculty; facilities; and institutional support.

The curriculum criteria are described in the *Criteria for accrediting engineering programmes* manual [11][12] and states three main requirements:

a) One year of a combination of college level mathematics and basic sciences (two academic semesters equivalent to 30-32 credit hours (Cr hrs).
b) One and one-half years of engineering topics, consisting of engineering sciences and engineering design (45-48 Cr hrs).
c) A general education component that complements the technical content of the curriculum.

To fulfil the requirements, the CE curriculum comprised a total of 135 Cr hrs with 20 Cr hrs for maths and 12 for basic science. The distribution of topics and credit hours is shown in Table 1.

Table 1: Distribution of credit hours in the CE curriculum.

Subject area	Topics	Credit hrs	Total
Mathematics, physical and natural sciences	Mathematics Physics and chemistry	20 12	32
Technical content	Technical core Technical elective Industrial training Design project Computer science	37 12 1 3 21	74
Other courses	English and humanities Free humanities/social sciences Ethics and professional issues Free business elective	20 3 3 3	29

The computer engineering component in the updated curriculum is covered by engineering and computer science core and elective courses, senior project and industrial training. It has 40 Cr hrs as core courses, and 12 Cr hrs as elective courses. The senior project is three Cr hrs, which enable the students to use both their knowledge and skills in solving engineering problems. The remainder of the updated CE curriculum credit hours include ethics and professional issues, a business elective, humanities and social sciences.

IEEE STANDARD

The ACM/IEEE 2016 CE standard was adopted for benchmarking the contents of the course [2]. The standard categorises the main subjects into 12 bodies of knowledge (BoK). Each BoK is divided into units, with a list of topics. The ACM/IEEE BoKs are as follows: circuits and electronics; computing algorithms; computer architecture and organisation; digital design; embedded systems; computer networks; preparation for professional practice; information security; signal processing; systems and project management; system resource management and software design.

Detailed mapping was performed to ensure that the number of hours required for each subject was covered in the courses. This mapping benefited the programme development process in three main ways. First, several missing topics in the old curriculum have been identified (software engineering, cybersecurity, databases, algorithms, embedded systems). Second, overlaps between some courses have been detected (e.g. signal and systems and digital signal processing). Third, a possibility to merge courses has been raised (computer network courses).

Consequently, after the mapping, the committee took several actions based on the mapping results. Some courses were rearranged and new courses were introduced to accommodate the missing BoK topics. Furthermore, the overlap or similarities between courses were adjusted by revising the different courses and redistributing the topics among the courses. There was a case where three courses were revised and merged into two courses. While conducting the mapping, the committee did not face any conflict between following ABET curriculum criteria and ACM/IEEE standard requirements.

COMPARISON WITH OTHER UNIVERSITIES

Benchmarking against national and international universities is an essential part of the curriculum development process and it is a step toward learning good practice, and hence work on improvements. The process started with selecting seven CE curricula, from different universities, as benchmarks; namely: King Fahd University of Petroleum and Minerals (KFUPM); the University of Illinois at Urbana-Champaign, USA; the University of Wisconsin Madison (UW), USA; the University of New South Wales, Australia (UNSW); the National University of Singapore (NUS); McGill University, Canada; and the University of Kent, UK.

Their curricula followed different academic accreditation systems. Three of the universities are ABET-accredited and this selection informs from applying ABET criteria experience. In addition, the curricula that follow other accreditation commissions were selected for comparison and to learn different implementations of CE curricula worldwide.

For instance, the University of Kent follows the Institution of Engineering and Technology (IET), McGill University follows the Canadian Engineering Accreditation Board (CEAB), the NUS follows the Institution of Engineers, Singapore, and the UNSW follows the Engineers Australia organisation. It was found that the percentage of similarity between the developed curriculum and the benchmarked ones was high; as illustrated in Table 2.

Table 2: Comparison between the UOB CE curriculum and other benchmarked curricula.

Benchmark curriculum	Programme length Years -semesters	Credits	Overall similarity elective, cores	College/ department	Number of electives	Percentage of science/ mathematics
UOB CE	4 - 8	135	-	IT/CE	4 technical/ 2 free	23.7
KFUPM	4 - 8 (+1 preparatory year)	133	88.6%	Computer Science, Engineering/ CE	6 technical/ 3 free	22
University of Illinois	4 - 8	128	84.1%	Engineering/ CE	27 technical/ 12 free	24.2
UW	4 - 8	120-121	88.6 %	Engineering/ Electrical, CE	7 technical/ 5 free	25.6
UNSW	4 - 12 terms	192 UoCs (6 UoCs per course)	88.6 %	Engineering/ CE	48 UoCs	18.75
NUS	4 - 8	160	81 %	Engineering/ CE	24 MCs technical/ 54 MCs free	14.5
McGill University	4 - 8	133	88.6 %	Engineering/ Electrical, CE	4 technical/ 4 free	23.3
University of Kent	3 - 6	390 Cr (15 per course)	77 %	School of Engineering	-	4

More comparable data are illustrated in Table 2, such as the length of the programmes in years and semesters, as well as total number of credits. By following ABET accreditation, approximately more than 60 percent of the credit hours are core courses required to fulfil the minimum requirement for mathematics, basic science and computer engineering. The remaining credit hours can be tailored to other requirements. Further, it was observed that the set of elective courses is based on the requirement of the local market, funded projects and faculty specialisation. Therefore, core courses that support the elective courses varied between the different universities.

STAKEHOLDER FEEDBACK

Close involvement of stakeholders so as to evaluate the curriculum and engage in providing ideas and rationale is essential. Curriculum development requires the input from various stakeholders, such as faculty, students, alumni, employers and even high educational authorities in some cases. The active and direct involvement of stakeholders will shape the curriculum towards being outstanding. The CE Department has an agile and flexible curriculum development process that allows partnerships with a range of stakeholders. Various methods are adopted to collect feedback from stakeholders, such as surveys, interviews, focus groups, and workshops.

Faculty Feedback

A survey has been carried out for the purpose of collecting feedback from faculty members in the Department regarding their academic profile, professional development, as well as teaching and assessment activities, in addition to their satisfaction with the facilities provided. The feedback collected from faculty members provided great input on the development of the CE curriculum, specifically in enriching theoretical and practical course material, revising intended learning outcomes, updating textbooks and related resources, and modifying some course assessment criteria.

Student Feedback

Current students were engaged in focus groups with external and internal stakeholders to share their opinions and comments on the development of the curriculum. In addition, an exit survey for senior students that are about to graduate is carried out twice a year during the end of each semester to be able to measure the overall programme experience. The survey reflects the graduating students' satisfaction of the curriculum and solicits their assessment of the knowledge and skills acquired.

The data gathered from the focus groups and surveys have contributed to the development of the practical part of the courses. Moreover, the feedback resulted in adding more elective courses that tackle latest trends in the present digital transformation era.

Alumni Feedback

Alumni involvement contributes significantly to the development of any curriculum. Hence, the CE Department conducts a survey of its alumni frequently. The survey is intended to solicit feedback from graduates regarding their readiness for the market, as well as knowledge and skill competencies required to become competitive in the workplace. The survey generated data that contributed to the development of the curriculum, especially in terms of aligning the courses with the current and future market needs.

Employer Feedback

The Department has a Programme Industry Advisory Committee (PIAC) that is made up of employers as main stakeholders plus alumni and other representatives from the market. A number of meetings, focus groups and workshops are carried out to collect feedback from the members of the committee. Suggestions evolved around enhancing the students' communication skills, creativity and ability to *think out of the box*; their critical thinking and analysis; their ability to translate technical knowledge into an actual useful product; and other programming and Web development skills. The discussions with the employer and other representatives enriched the curriculum and aligned the course outcomes along with the programme outcomes with the employer and market needs.

OTHER CHALLENGES

Institution Objectives, Requirements and Resources

Students in UOB study four compulsory courses: Arabic language skills; Islamic culture; modern history of Bahrain and citizenship; and human rights courses, for a total of 11 Cr hrs. The UOB vision and mission are updated according to the global awareness of current and future requirements, and academic programmes should align their vision accordingly. For instance, UOB has a vision to become an entrepreneurial institution with emphasis on innovation and technology. These values are embedded in the CE curriculum in many course projects, the senior project and in newly added business courses.

Placement of the Programme within the Institute

The CE programme could be located in different colleges and departments in academic institutions. For example, the programme could be in a college of engineering, department of electrical and electronics engineering, department of electrical and computer engineering, computer science and electronics engineering or in a standalone CE department. Another example is the College of IT, Department of CE, as in the University of Bahrain. The placement of the programme determines the vision and subject focus, and consequently the courses and skills required.

Faculty Size and Expertise

This has direct impact on the number of students enrolled and the number of courses offered. More importantly is the effect on elective courses selected to be in the curriculum. In the process of selecting elective courses, a request was sent to all faculty members to offer courses within their specialisation.

Student Background

The majority of enrolled students are graduated from public schools, where all science and mathematics subjects are taught in Arabic. Therefore, there is a language gap since the teaching language in UOB is English. To fill this gap, three English courses are included in the curriculum. Another challenge is computer and technology background knowledge, which varies in a range from moderate preparation to very low. This problem is solved by introducing an introductory course to CE, where the contents cover basic concepts, processes and components of computing systems, including principles of networking, mobile fundamentals and operating systems.

Funded Research

Many programmes that are located within an industrial environment and have a high academic reputation receive funds for scientific research. Faculty members involved in funded projects disseminate the knowledge gained to students through courses and design projects.

DEVELOPED CURRICULUM

In the first, second, and third year, the developed curriculum consists of basic science and mathematics courses, an introductory CE course, and electrical and electronics courses required to build the knowledge for the students. In the fourth year, there are four elective courses, a senior design project, business elective courses and free elective course. In addition, two core courses are taught. Shown in Figure 1 are the main courses by level. Other courses, such as humanities, university requirements, and English courses are not shown.

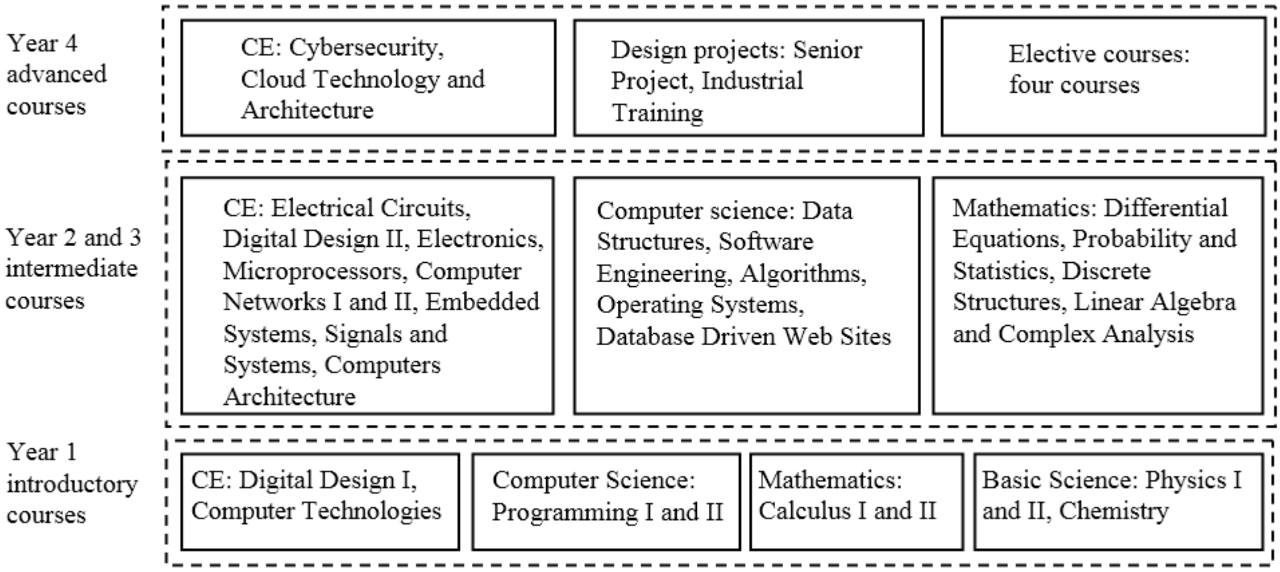

Figure 1: CE curriculum structure: levels and courses.

In summary, there are seven new courses. A new course called Computer Technologies is designed to be taught in the first semester, to introduce a wide range of knowledge areas of CE for the fresher. In addition, this course is designed to bridge the gap in knowledge of engineering and technology between school education and CE. In the old curriculum, the first course is the fundamentals of logic design in the second year.

Digital circuit design material is delivered using two courses, Digital Design I in the second semester of the first year, and then followed by Digital Design II in the first semester of the second year. Computer networking material is delivered as two courses in the second semester of the second year and followed by another course in the third year. A high number of CE graduates start their careers specialised in computer networks, and they can be employed easily in the local market, because of the high industry demand for a workforce in computer networks.

Introduction to Software Engineering is newly added in accordance with ACM/IEEE standards, to cover part of the area of system project engineering. A new course, entitled Embedded Systems, is included to cover many sub-titles, such as development environments for embedded software, resource aware programming, hardware programming, developing multi-threaded software, inter-process communication with shared memory and message passing, programming using real time operating systems, fault detection and testing, and fault tolerance and fault recovery. Included are applications, such as wireless sensor networks, Internet of Things (IoT), cloud servers, mobile interfacing and smart homes.

A course, entitled Database Driven Web Sites, was added to introduce the fundamental concepts of database management systems and the key technologies underlying the WWW that are used to develop dynamic Web applications. The knowledge and skills attained from this course were requested continuously by students and alumni, because they are additional skills, which increase students' employability. This course teaches how to build contemporary systems that integrate several technologies, such as IoT applications.

Another state-of-the-art course is Cloud Technology and Applications, which covers the technological issues in developing, deploying and utilising cloud computing. Topics include: resource virtualisation and its applications to computing; networking; storage and architectural layers of cloud computing; management and scheduling of cloud resources; and an overview of various industrial solutions. This course aims to equip students with additional knowledge for the market and for building comprehensive projects [13]. Students will be able to acquire professional certification and increase their employability. In the Kingdom of Bahrain, a government shift to adopt cloud services started in 2017 and employers announced the need for specialists in the field of cloud services and cybersecurity, in particular [14]. This course was chosen to be the core course for the reasons mentioned above. The prior knowledge to master this subject is covered in many courses, such as Programming, Computer Networks, Computer Architecture, and Databases.

Based on the ACM/IEEE standard, the Cybersecurity Core course was added to cover cybersecurity components, cybersecurity industries, cryptographic algorithms, cybersecurity architecture, security threat and risk assessment, e-services security, system cybersecurity, such as embedded systems, cloud computing security and IoT security. In ACM/IEEE, a BoK for computing algorithms is 30 hours, compared to the old CE curriculum where this was not covered. Therefore, a new course to teach algorithms was included. A business course was added to provide students with the necessary knowledge required in the workplace using different subjects (project management, entrepreneurship, marketing management, organisation management, business administration and financial accounting). Table 3 in Appendix 1 has a list of the distribution of all courses within the new CE programme.

The set of elective courses was selected to expand the students' knowledge in many CE areas, such as computer networks, digital design, cybersecurity and digital communications. The courses include IoT, Artificial Intelligence (AI), Computer Vision, Image Processing, Robotics, Data Mining and Machine Learning, Hardware Security Design and Industrial Automation. There is another factor that affects the choice of elective courses: the specialisations of the faculty members. Two courses, named Selected Topics in CE 1 and 2, teach the students any contemporary and emerging subjects. For the complete eight semesters developed plan with course prerequisites and full list of elective courses, refer to the UOB-CE Web site.

DISCUSSION AND CONCLUSIONS

The design of the curriculum streams students to graduate with majors in many areas, such as computer networking, embedded systems design, digital design, cybersecurity and cloud computing. The design has core courses in level 1, 2, 3 to the advanced level 4, and elective courses. The curriculum is characterised by flexibility in choosing courses (four technical CE courses, business subject course, free elective courses) and is tailored to different students' needs. New core courses added (e.g. Database Driven Web Sites, Cloud Technology and Applications, Cybersecurity) and elective courses (e.g. Data Mining and Machine Learning, IoT, Industrial Automation) will bridge part of the gap in the mismatch between academic programmes and the local marketplace because the set of courses chosen is required by the local service-based industry.

Based on the demonstrated experience in updating the CE curriculum, presented in this article are the main challenges encountered and possible implementations to tackle them. A framework for developing or updating an engineering curriculum was presented. The framework is summarised as follows:

1. For the purpose of receiving feedback and requirements in the academic programme, and in particular on curriculum, start with surveys for students, alumni, employer and faculty.
2. Based on the results, arrange for meetings, focus groups to gather more data.
3. Follow an academic standard if available and use it as a guide in the development process.
4. Align with the institution vision, mission and learning outcomes.
5. Abide by national quality assurance requirements.
6. Strictly follow the criteria of the accreditation commission.
7. Conduct a comparison between the first drafts of the designed curriculum with number of accredited programmes worldwide.

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BIOGRAPHIES

Hessa Al-Junaid received the BSc and MSc degrees in electrical engineering from the University of Bahrain, in 1996 and 2001, respectively, and holds a PhD degree from the University of Southampton, UK in 2006. She holds a postgraduate certificate in academic practice from the York St John University, UK in 2008. Dr Al-Junaid was a chairperson for the Computer Engineering Department. Her research interests include modelling and simulation of mixed-signal circuits and systems and mixed-disciplinary systems, brainwaves modelling and analysis for brain machine interface and robotics applications. Dr Al-Junaid is an active member in the Bahrain Society of Engineers and in the Institution of Engineering and Technology (IET), UK. She is a fellow of the Higher Education Academy (HEA), UK.

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Jalal Khlaifat obtained a BSc in computer engineering from the University of Bahrain in 2007. In June 2009, he joined the Department of Computer Engineering as a graduate assistant, and in 2011 he completed the MSc degree at the University of Sheffield. In 2016, he received a PhD degree from the University of Edinburgh for his thesis, *Towards the development of flexible, reliable, reconfigurable, and high-performance imaging systems*. He was an active member in the Institute for Integrated Micro and Nano Systems. His research interests include reconfigurable computing, image processing and intelligent systems. In 2018, Dr Khlaifat became a fellow of the Higher Education Academy (HEA), UK.

Aisha Bushager is an assistant professor in the College of Information Technology at the University of Bahrain, and at present is Head of the Computer Engineering Department. Dr Bushager holds an MSc in e-business technology from the University of Gloucestershire in the UK, and received her PhD in electrical and electronics engineering from the University of Southampton, UK. Dr Bushager's publications include topics, such as modelling security protocols and evaluating system security using transaction level modelling and SystemC; privacy and security of management information systems; cryptocurrency security and privacy; and risk management.

APPENDIX 1

Table 3: List of courses grouped according to ACM/IEEE subject areas.

Subject area	Course title	Cr hrs	Total
Electrical and computer engineering	Computer Technologies	3	40
	Digital Design I	3	
	Digital Design II	3	
	Electrical Circuit Analysis	3	
	Electronics	3	
	Microprocessors	3	
	Data Communications Networks	3	
	Embedded Systems	3	
	Computer Networks	3	
	Signals and Systems	1	
	Computer Architecture	3	
	Professional Issues and Ethics	3	
	Cloud Technology and Architecture	3	
	Cybersecurity	3	
Technical elective	Four courses to be selected from a list	12	12
Computer science	Computer Programming I	3	21
	Computer Programming II	3	
	Data Structures	3	
	Introduction to Software Engineering	3	
	Operating Systems	3	
	Database Driven Web Sites	3	
	Analysis and Design of Algorithms for Engineers	3	
Design project	Industrial Training	1	4
	Senior Project	3	
Mathematics	Calculus I	3	20
	Calculus II	3	
	Discrete Structures I	3	
	Differential Equations	3	
	Probability and Statistics	3	
	Signals and Systems	2	
	Linear Algebra and Complex Analysis Variables	3	
Basic science	General Physics I	4	12
	General Chemistry I	4	
	General Physics II	4	
English and humanities	Language Development I	3	20
	Language Development II	3	
	Human Rights	2	
	Arabic Language Skills	3	
	Technical Report Writing	3	
	Modern History of Bahrain and Citizenship	3	
	Islamic Culture	3	
Free elective	Humanities/Social Sciences	3	6
	Free elective for computer engineering	3	