Computer Science Education Facing Unconventional Odds: Case Studies from the Arab World

Sherif G. Aly, *The American University in Cairo,*
Karima Echihabi, *Mohamed VI Polytechnic University, Ben Guerir, Morocco*,
Seif Eldawlatly, *The American University in Cairo and Ain Shams University, Cairo*.
Khaled Shuaib, *United Arab Emirates University, Abu Dhabi, United Arab Emirates*,
Joe Tekli, *Lebanese American University, Byblos, Lebanon*

Computer Science has been rapidly evolving at unprecedented rates over the past decade. As curricular guidelines are being developed by the CS2023 ACM/IEEE/AAAI taskforce, this article attempts to emphasize how computer science education is happening in a diverse area of the world, namely the Arab World. We focus on four regions within the Arab World which are Egypt, the Levant, the Arabian Gulf, and Northwest Africa. We present the spectrum of higher education in each region focusing on computer science education. Additionally, leading programs are highlighted as case studies indicating how each program copes with ongoing computer science education challenges.

INTRODUCTION

The three most prominent bodies in computing, namely IEEE, ACM, and AAAI have teamed up to form a taskforce of worldwide experts in computing to envision how the guidelines of computing education CS2023 will look like. Built on CS2013, the new guidelines are intended to cater to a worldwide audience, capture state-of-the-art happening in computing education, and have a glimpse into the future of computing education. As the state-of-the-art guidelines are intended for a global audience, it is critical to expose the landscape of computer science education happening around the globe. Many computer science programs around the world are designed while benchmarking themselves against worldwide standards

PHOTO: ©SHUTTERSTOCK/AHMED HAMDY HASSAN

A computer lab in Sharurah, Saudi Arabia.

and accreditation criteria, such as the Accreditation Board for Engineering and Technology (ABET). There is a huge variance in the ecosystems surrounding such programs, including language barriers, economic differences, and most importantly, varying demographics.

The Arab World is composed of extremely diverse cultures spanning the Atlantic Ocean in the west to the Arabian Gulf in the East. The region is characterized by a huge variance in the abundance of resources that support the education system. For example, according to ABET, Egypt as the most populous nation of the Arab world currently has five computer science ABET-accredited programs while Lebanon which is about fifteen times smaller in population has six [1].

Countries in the region have historically been affiliated with extremely diverse educational systems, specifically with the French, British, and US educational systems. To familiarize the worldwide community with practices happening in computer science education around the world, this article attempts to expose some of the ecosystems surrounding computer science education in the Arab World. Specifically, computer science education in four prominent regions of the Arab World is discussed: Egypt as the most populous and centric region of the Arab World, the Levant region in the north east, the Arabian Gulf region in the east, and last but not least, Northwest Africa. A glimpse is provided about the nature of the ecosystems of education in each of those regions, with some examples of how computer science education is conducted, some of the innovations that are happening in delivery given the exponential growth happening in the domain, and the constraints imposed on the size of curricula in undergraduate education.

EGYPT

Higher Education in Egypt: Egypt is the most populous country in the Arab world with a population of more than 103 million [20]. It is a young nation with approximately thirty-five percent of its population below eighteen years old. In 2021, the total number of enrolled students in Egyptian universities was around 2.5 million students in about sixty universities with almost equal percentage of males and females (47.36% males and 52.64% females) [77]. The number of graduates in 2020 reached around 480,000 graduates [77].

Computer Science Education in Egypt: Computer science education in Egypt dates back to the late 1970s and early 1980s with the offering of computer science undergraduate programs

Computer science education in Egypt dates back to the late 1970s and early 1980s with the offering of computer science undergraduate programs at the American University in Cairo, Cairo University, and other universities. Today, computer science programs in Egypt attract some of the top students engaging in university education …

at the American University in Cairo, Cairo University and other universities [2,37]. In the 1980s, autonomous departments for Computer Science and Computer Engineering were established under schools of sciences and engineering in different universities [2,37]. In the mid-1990s, dedicated schools of computer science were established [4,39]. Today, computer science programs in Egypt attract some of the top students engaging in university education [5]. There are more than 50 schools of computer science in public, private and national non-profit universities [31]. Other programs have specialized concentration programs in Cyber Security, Digital Multimedia, Software Engineering, Bioinformatics, and Artificial Intelligence. A larger than usual demand is driven by higher than average salaries in the domain [12].

To cope with the recent advances in Artificial Intelligence (AI), many computer science schools in public universities in Egypt started to offer special programs dedicated to AI [36,39]. Multiple universities in Egypt have recently offered undergraduate data science programs or concentrations—for example, at the American University in Cairo and the German International University [13,38]. This is almost at the same time of establishing professional diplomas in data science and big data technologies at other universities [16,30,37].

The Case of the American University in Cairo: The American University in Cairo (AUC) is ranked second in Egypt and 19th in the Arab region according to the Times Higher Education ranking of Arab universities [76]. The AUC, established in 1919, is known for its diverse international community representing more than 60 countries [3]. It offers more than 39 undergraduate programs in addition to more than 50 graduate programs [3]. The AUC provides undergraduate students with an opportunity to spend a semester abroad at more than 230 universities in Europe and the US including top universities such as the University of Geneva, University of Edinburgh, The University of California, Berkeley, and University of Colorado at Boulder [10,11,74].

The Computer Science program at the AUC was the first ABET-accredited Computer Science program in the Arab World [1]. The program represents one model of a program in Egypt that is adapting with agility to cope with very rapid changes in the field. The program has been structured with a vision to be Student-Oriented, Popular, Research Intensive, Industrially Aligned, Technologically-current, and Experiential (SPRITE) [84]. The program is supported with a very rich liberal arts education adopted by the university, focusing on providing students with the skills and the vision needed to tackle societal problems. It is co-offered with a counterpart computer engineering program offered by the same department to stimulate cross-specialty and systems-based collaboration. At least sixty-six required credit hours of computing courses along with very strong mathematical foundations are part of the study program.

In addition, to cope with the rapid evolution of computer science that currently represents a significant challenge to computer science education, the program promotes essential research skills of students through projects assigned in multiple courses. Senior capstone projects are designed to have a research component that leads in many cases to publications. As part of the capstone project, sessions on research and entrepreneurship are given to students. About half of the capstone projects are co-supervised by key industrial partners to wean students into the industrial landscape. The program requires students to undergo a "micro co-op" eight-week-long industrial training with a very high expectation of technical rigor. Students are incentivized to start their internships as early as their second year of education and this is enabled through an early-maturity pedagogical approach, which helps students get exposed to the latest technologies used in the industry. Each batch of graduating students are given the opportunity to pitch their key skillsets to employers through professional one-minute video graphs that are promoted by the program. It is noteworthy that other computer science programs in Egypt adopt similar strategies focusing on boosting the research skills of the students in addition to requiring industrial training as a graduation requirement.

Governmental Initiatives to Foster Computer Science Education/Training: The Egyptian government has established multiple initiatives to provide computer science training in advanced fields including AI and data science. In 2019, the Egyptian government established the National Council for Artificial Intelligence with the task of outlining the national AI strategy of Egypt [63]. In 2020, the Egyptian government launched the Digital Egypt Builders initiative with the target of training 1000 university students, who are majoring in either computer engineering or computer science, on practical aspects of AI, data science and cybersecurity [29]. Finally, in 2021, and in partnership with Amazon Web Services (AWS),

the Egyptian government trained 500 individuals on using AWS big data and data analytics tools [68].

THE LEVANT

Higher Education in the Levant: The Levant region consists of Lebanon, Palestine, Syria, Jordan, and Iraq, including a total of 2 million university students. Most renowned universities in the Levant are national public institutions, except for Lebanon which boasts a private educational sector that rivals its public counterpart. Lebanon's private universities mostly follow the American and French models and include some of the top higher education institutions in the region.

Computer Science Education in the Levant: With the lack of accurate statistics, we hypothesize that about 400 thousand students in the Levant are enrolled in Computer Science/Engineering (CS/E) and related IT disciplines, amounting to almost 20% of the total student body (according to combined international students' statistics from [9]). A person working as a CS/E professional in the Levant countries for which we have data, namely Lebanon, Jordan, and Palestine, earns around USD 2,500, where salaries range from USD 800 (lowest) to USD 5,500 (highest) (cf. Table 1) [71]. The primary type of CS/E industry is software development.

The Case of the Lebanese American University: The Lebanese American University (LAU) was founded as the American School for Girls in 1835, and the institution evolved into a full-fledged university in 1973 and became the Lebanese American University in 1995. It currently boasts three campuses in Byblos and Beirut housing seven academic schools and more than 300 faculty and 8,000 students. LAU currently holds the #1 position in Lebanon and the #16 position in the Arab region according to Times Higher Education [76]. Founded in 1995, the School of Engineering (SOE) offers B.E. degrees in computer engineering, electrical engineering, and mechatronics engineering, with M.Sc. degrees in computer and electrical engineering. The B.E. degree covers 150 credits and typically spans over five years of study. The SOE has established and is initiating a battery of innovative solutions to promote CS/E education, which can be mirrored in other universities in the region.

The SOE has established strong collaborations with major industry partners in the CS/E sector, offering internships to selected students working on state-of-the-art projects and technologies, and providing feedback regarding the most recent technological trends in the market. The latter is essential in the fast changing and dynamic field of CS/E, where academia must always keep-up with the latest frameworks, programming languages, and software and hardware design practices in industry. SOE has established a strong collaboration with BMW Group since 2018 [54] targeting the fields of software development, robotics, and artificial intelligence. This has allowed more than 160 top students to conduct their internships at the automotive giant's main seat in Munich [46]. SOE has also initiated and organized a joint LAU-BMW Workshop Day on Vision Intelligence and Robots Applications (VIRA 2018-21) [80], allowing LAU-BMW interns to present their projects. BMW Group has also donated to LAU a special edition 2020 hybrid electric i8 Boxster, to use for collaborative academic and research projects. High-impact hackathons and competitions are organized frequently with industrial partners for exposure and experience sharing, e.g.: First Lego League (FLL) 2019 international robotics championship [40], organized for the first time in the MENA region (1,000 participants); National Education Robotics Day (NERD) Open 2018 (400 participants); NERD National 2019 (700 participants) [41]; LAU CASE Competition 2022 in collaboration with IBM (410 applicants) [8]; and BMW Group Beirut AI Hackathon 2019 in collaboration with Nvidia and Oracle (hosting 74 participants from eight universities in a 24-hour machine learning hackathon).

To address the need for computational resources, LAU's academic and research body will soon have access to high-performance computing through a project initiated by the Geneva-based European Organization for Nuclear Research (CERN) to donate and help set-up a Tier-2 data center in Lebanon [28], as part of its High-Performance Computing for Lebanon (HPC4L) project [42]. It will be governed by a consortium of Lebanese universities in addition to the National Council for Scientific Research (CNRS-L). LAU will lead the system administration, offering a unique learning experience for undergraduate and graduate students. Additionally, student entrepreneurship is central in CS/E due to this field's fast changing and evolving nature. In this context, LAU has recently launched the Vertically Integrated Project (VIP) framework in Fall 2021, thanks to a grant from the US Department of State Middle East Partnership Initiative (US-MEPI). Designed by Georgia Tech, the VIP consortium includes 44 academic institutions from 13 countries [56], the majority of which are based in the US, allowing student teams from across the disciplines to collaborate

Table 1: Number of university students, including CS/E students

	Lebanon [54]	Palestine [39]	Syria [62]	Jordan [38]	Iraq [42]
Number of University Students	222,000	221,000	500,000	267,000	850,000
Number of CS/E Students (estimated [59])	44,400	44,200	100,000	53,400	170,000
Average salary for CS/E Graduate (in USD)	2,500	2,630	NA	2,780	NA

on innovative projects [55]. LAU expanded the VIP framework to a VIP+ model, incorporating an entrepreneurship component that falls under the MEPI Tomorrow Leaders' College to Work Pipeline (TLP) [79], encouraging them to innovate and create their own startups. This initiative was spearheaded by the dean of the SOE: a computer engineering faculty who specializes in computer vision and machine learning, where most current VIP teams are developing projects revolving around CS/E. A related initiative includes the launching of the LAU Fouad Makhzoumi Innovation Center (LAU FMIC) in 2020, providing an incubation hub which aims at fostering student entrepreneurship endeavors.

SOE has launched undergraduate research courses in every engineering program, namely in computer engineering, mechatronics engineering, and electrical engineering, and a research methods course in the honor's program. The former allows motivated students to get a foretaste of research activities. Since 2018, more than 40 undergraduate students have participated in research projects, most of them publishing their papers in international conferences or journals. Many projects are funded by CNRS-L research grants awarded to the supervising faculty. Moreover, SOE motivates students to launch academic and professional clubs, allowing them to highlight their scientific and social talents, and engage in extracurricular projects, workshops, boot camps and other initiatives [58, 73]. SOE currently houses 5 clubs revolving around CS/E, including IEEE student chapter, Google Developer Student Club (DSC), Robotics club, Artificial Intelligence club, and Logistics Automation club.

Governmental Initiatives to Foster Computer Science Education/Training: In addition to efforts conducted at the university level, there have been efforts to further promote and solidify CS/E education at the high school and middle school levels in Lebanon, such as the introduction of computer science classes in the middle school classes (or cycle 3) of 553 of the 875 public schools according to the Center for Educational Research and Development [57]. While most private schools already offer computer science courses, nonetheless, a computer science education bill was recently passed by the Lebanese Parliament in 2022 making computer science education compulsory in all high schools in the country, mandating the need to overhaul the curriculum to adapt to the requirements of modern education systems [57]. Moving in the direction of universities and schools without borders, following an agile stackable credentials model, would be the next evolutionary step in further improving CS/E education in the Levant.

THE ARABIAN GULF

Higher Education in the Arabian Gulf: Countries which are members of the Gulf Cooperation Council (GCC) are Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE). The education sector in these countries has grown and changed in the last two decades to address local and global challenges and provide quality education to students. Several universities in this region have been evolving rapidly while focusing on the quality of produced research and delivered education to become among the top 300 ranked universities around the world (according to several rankings including the QS World University ranking of 2024) [69]. These include, among others, the UAE University, Khalifa University, Qatar University, King Fahd University of Petroleum and Minerals and King Abdulaziz University.

Computer Science Education in the Arabian Gulf: Computer science programs have been at the core of the education growth in the Arabian Gulf region in line with the new emerging interest in fields such as Artificial Intelligence, Robotics, Data Science, Cloud Computing and Cyber Security. Table 2 shows examples of public and private universities offering undergraduate computer science programs.

Table 2: Examples of Universities Offering CS Programs in the GCC.

Country	Examples of universities offering an undergraduate CS program
Bahrain	University of Bahrain, British University of Bahrain
Kuwait	American University in Kuwait, Kuwait University
Oman	Sultan Qaboos University, German University of Tech. in Oman
Qatar	Qatar University, Carnegie Mellon University in Qatar
Saudi Arabia	King Abdul Aziz University, King Saud University, King Fahd University of Petroleum and Minerals, Effat University
United Arab Emirates	UAE University, Khalifa University, NYU-AD, Birmingham University, American University of Sharjah, University of Sharjah

The majority of the offered undergraduate computer science programs in the GCC countries align their program offering with the ACM/IEEE 2020 computing curricula. ABET accreditation of computer science programs is usually targeted in addition to accreditation by the local authorities within each country. Some of the programs are offered as a single track while other programs include one or more concentrations/specializations. For example, the computer science programs at the UAE University and King Saud University [14,15] provide students with a basket of elective courses to choose from but do not offer any concentrations. On the other hand, the programs offered by Khalifa University [19] and Effat University [18], for example, offer two concentrations, Artificial Intelligence and Cybersecurity. The majority of offered computer science programs are composed of a curriculum between 120 and 140 credit hours.

The Case of the United Arab Emirates University: Looking at the computer science program [14] at the UAE University, which is ranked 7th in the Arab World according to the Times Higher Education ranking [76], we can identify a few distin-

guishable innovative characteristics. The program requires all students to complete a course on the 4th industrial revolution which introduces students to emerging computing topics and related problems. This course also includes a technical English language tutorial component to enhance students' technical communication skills. In addition, all students complete a course called "Entrepreneurship in IT," that is tailored to enhance students' skills in IT based venture creation and related areas of interest. Students, through this course, can link with the UAE University science and innovation park which acts as an incubator. The program also offers the students a "Special Topics in Computer Science" course that can have different content each offering depending on special requests. New proposed changes to the program are being studied to enhance future offering. This incorporates more flexibility and adaptability to enable graduates to meet the fast-changing business and market requirements landscape in the UAE in various areas of interest such as Space, AgriTech, Biotech, Energy, Healthcare and Cyber Security. The new proposed changes to the computer science program include the following:

- a minimal core of computer science courses with tailored math courses, creating specialization tracks relevant to market needs,
- embedding ethics as modules throughout the curriculum,
- embedding AI throughout the curriculum in addition to offering other advanced related courses (computer vision, natural language processing, computational analysis, bioinformatics….etc.) [19],
- introducing what the College calls "Technopreneurship," a technology-based entrepreneurship program to help students develop entrepreneurial and technology-based mindset and skills to bring their ideas to life.

The program will start as early as the first year of studies and continue seamlessly throughout the students' academic journey. This can replace what is commonly known as the capstone project, and finally, allowing students to complete a minor from another discipline to broaden their breadth knowledge.

Governmental Initiatives to Foster Computer Science Education/Training: Arabian Gulf governments have introduced multiple mechanisms to promote computer science education in the region, focusing on recent trends in computer science. For instance, in the UAE, the Ministry of Education (MoE) Commission for Academic Accreditation (CAA) accredits programs based on a very rigorous set of criteria and standards. The CAA Standards [25] introduced certain requirements to be fulfilled by computing programs making them more innovative and accommodating of new emerging trends. For example, the Standards mandate that AI and Data Science,

[I]n Northwest Africa, post-secondary programs in computer science are delivered mainly by universities and engineering schools. To select the top programs in Northwest Africa, we conducted a series of interviews with well-established computer science academics in Algeria, Morocco, and Tunisia.

as relevant to each discipline, be covered either as separate courses or as modules infused into other courses. In addition to the AI and Data Science requirements, the Standards mandate that all computing programs offer a 12-week Internship experience and that at least 50% of the program's contact hours of computer science major courses have either associated labs or applied components.

NORTHWEST AFRICA

Higher Education in Northwest Africa: The Maghreb's (Northwest Africa) population is estimated at 105 million inhabitants with 88% living in three countries: Algeria (44 million), Morocco (37 million) and Tunisia (12 million) [83]. The number of students enrolled in technology-related post-secondary studies exceeds 253,000 out of 1,447,000 higher education enrollments in Algeria [64], 40,000 out of 1,170,000 in Morocco [60] and 26,000 out of 234,000 in Tunisia [72]. Higher education is offered through a network of university and non-university public and private institutions, which mainly follow the three-cycle License-Master-Doctorat (LMD) structure recommended by the Bologna Process [35]. This process is based on the European Credit Transfer and Accumulation System (ECTS) that awards credit based on total student work not just direct instruction or "contact" hours, as is the case in the US system. The typical conversion rate is that one US credit is worth 2 ECTS credits [47]. Institutions that follow the Bologna process offer 3-year bachelor's (180 ECTS credits over 6 semesters), 1-year or 2-year master's (up to 120 ECTS credits over 4 semesters) and doctoral degrees. Each semester lasts 14-16 weeks and is worth 30 ECTS credits, where one credit corresponds to 25 hours of work per semester including lectures, labs and homework [82]. Exceptions are engineering schools that offer 5-year degrees (300 ECTS credits over 10 semesters), considered equivalent to a master's degree, and institutions following the Anglo-Saxon system which deliver 4-year bachelor's degrees (136 US credits over 8 semesters), where one US credit corresponds to one hour of direct instruction and at least 2 hours of work outside of the classroom, which amounts to about 50 hours of total work per semester. Public universities adopt an open access policy while public engineering schools and private institutions follow a rigorous selection process. All high-school graduates have the right to free-of-charge public university education, but admission to specific programs depends on available spots, and the student's preferences, grades and geographical location. Most programs are delivered in French as it is widely used in the private and public sectors.

Computer Science Education in Northwest Africa: Post-secondary programs in computer science are delivered mainly by universities and engineering schools. To select the top programs in Northwest Africa, we conducted a series of interviews with well-established computer science academics in Algeria [48,51], Morocco [52] and Tunisia [49,50]. We did not rely on the public rankings because they tend to favor large public institutions established in the fifties and sixties whereas the best computer science programs, in terms of the high caliber of entering students, the quality of teaching, and the employability of the graduates, are offered by private universities and engineering schools established in the last two decades.

Top programs in Algeria include those offered by l'Ecole Nationale Supérieure d'Informatique, Houari Boumedien University of Science and Technology and Oran 1 University. In Morocco, the leading institutions are Al Akhawayn University (AUI), l'Ecole Nationale Supérieure d'Informatique et d'Analyse des Systèmes (ENSIAS) and Mohammed VI Polytechnic University (UM6P). In Tunisia, prominent schools include l'Ecole Nationale des Sciences de l'Informatique, l'Ecole Supérieure des Communications de Tunis, l'Ecole Nationale d'Ingénieurs de Sfax, and l'Ecole Nationale d'Ingénieurs de Sousse.

There are three main challenges that face computer science education today in the Maghreb. First, all private and public institutions operate under the pedagogical authority of the Ministries of higher education, thus institutions have little governance in putting in place truly transformational innovations. The only exception is AUI in Morocco which was established by a special royal degree [7] that grants it total autonomy in delivering educational programs that are officially recognized, independently from the Ministry of Higher Education regulations. Second, the slow economy and complex bureaucracy lead to few highly qualified and lucrative positions and thus a severe brain-drain. In Morocco alone, 600 qualified computer professionals leave the country every year [17]. Third, despite the high number of students applications and growing interest in technology, computing programs have a limited number of spots due mainly to budgetary constraints and a shortage of qualified computing faculty.

Countries [in Northwest Africa] have launched several initiatives to improve the higher educational ecosystem, but many failed due to a blurry vision, absence of close monitoring, lack of funding, or political divergences. To overcome these difficulties, governments have established national advisory bodies to help the Ministries of Higher Education identify and implement the right strategies.

The Case of Three Pioneering Institutions in Northwest Africa: In terms of innovation in computer science education in general, three institutions particularly stand out: AUI and UM6P in Morocco, and the University of Sousse in Tunisia.

As a liberal arts institution, AUI has tailored its Bachelor of Science in Computer Science, accredited by ABET since 2009, to provide solid training in computer science with the option to minor in non-technical fields. All core computer courses have practical labs, and optional complementary training is offered during the last semester to equip students with first-hand practical experience in hot areas such as cybersecurity, distributed systems, or big data analytics. Students can receive credit for courses taken elsewhere, including online, if they are offered as credit courses within a university. Some professors have cautiously experimented with stackable credentials allowing students to take some course modules through online platforms, but the student assessment is conducted by the professors themselves, to ensure that students achieve the Intended Learning Outcomes for each course. Students are required to complete one internship and one capstone project and can combine both to conduct a more extensive project in industry or engage in a research thesis.

As a research-focused institution, UM6P designed its undergraduate program to prepare students to embark on innovation-driven careers. The School of Computer Science offers an undergraduate program that teaches students fundamental concepts in computer science and equips them with practical skills through learning-by-doing modules, leveraging state-of-the-art computing facilities and a digital learning lab. Courses in distributed systems, big data analytics, and cybersecurity are taught in the final two years of study by professors who conduct research in these areas. Students must undertake two internships in industry, two applied projects within the university and a one semester capstone project in a company or research laboratory. Students are also encouraged to engage in entrepreneurial activities thanks to a rich startup ecosystem which includes an entrepreneurship academy, a business incubator, an accelerator program and an investment firm [33].

The University of Sousse has also invested in many initiatives to encourage pedagogical innovations in its undergraduate computer science program. The learning lab supports professors in delivering MOOCS and designing courses based on peer-evaluation and flipped and hybrid classrooms [85]. The university also offers "co-construction" degrees that are co-designed with local industry, and government and non-government organizations to better align educational requirements with local market needs [81].

Governmental Initiatives to Foster Computer Science Education/Training: Countries have launched several initiatives to improve the higher educational ecosystem, but many failed due to a blurry vision, absence of close monitoring, lack of funding or political divergences. To overcome these difficulties, governments have established national advisory bodies to help the Ministries of Higher Education identify and implement the right strategies. Such bodies include the Conseil National d'Education et de Formation (CNEF) in Algeria [24], the Conseil Supérieur de l'Education, de la Formation et de la Recherche Scientifique (CSEFRS) in Morocco [27] and the Conseil Supérieur de l'Education et de l'Enseignement (CSEE) in Tunisia [26]. In 2023, a new national plan PACTE ESRI 2030 [67], has been launched in Morocco to accelerate the transformation of higher education, including the adoption of innovative curricula [32]. Acknowledging the strategic importance of emerging fields such as Artificial Intelligence and Cybsersecurity, academic institutions are establishing specialized educational and research programs such as l'Ecole Nationale Supérieure d'Intelligence Artificielle in Algeria [6], the UM6P AI Movement [22] and Center for Cybersecurity and Privacy [78] in Morocco, and a number of educational programs in Tunisia. Governments are also setting up national strategies and legal and regulatory frameworks around these topics [61,62,70]. In addition, Morocco has strengthened its digital sovereignty with a world-class data center and supercomputer [59]. Governments are also investing in the internationalization of higher education by offering dual degrees, exchange, and capacity-building programs such as Erasmus+ [34] and Horizon Europe [45], as well as the establishment of transnational programs such as Ecole Centrale Engineering School [23] and Cardiff Metropolitan University [21].

While computer science programs in the region train students to be able to work in R&D, enterprises or at the end of the value chain running computing projects, most graduates embark in the last two career tracks and many move into project management. The best and brightest graduates are often hired by R&D centers overseas such as Amazon, Facebook, Google,

[M]ultiple universities in the region are going through massive capacity building initiatives aimed at allowing advanced projects and research on computationally expensive tasks.

IBM, Microsoft, and Oracle. The reason is the lack of such opportunities locally. Hopefully, this trend will be limited with the opening of new R&D labs such as the Oracle Research Lab in Casablanca [66] and the growing start-up ecosystem.

LOOKING AHEAD

With an ever-expanding knowledge in the computer science domain, academic programs are finding it challenging to provide enough know-how and experiential training that can support the transition of students gracefully into the job market. As new Computer Science curricular guidelines are now in the making, it is important to highlight how computer science education and innovative practices are happening around the world. In this paper, we presented how universities in four regions of the Arab World are adapting fast to enable computer science students to be better prepared for the job market. Better practices from Egypt, the Levant, the Arabian Gulf, and Northwest Africa demonstrate how diverse the Arab World is in terms of its educational systems, as well as in the various innovative approaches taken by both public and private universities to prepare computer science graduates for the job market.

In recent years, the Arab World has faced challenges in terms of political and societal unrest that has hindered the advancement of academic and industrial efforts. Another big challenge is the lack of resources and reliance on student tuition to advance computer science education, which is extremely limiting and fragile. Additionally, one of the lessons learned throughout the evolution of this case study is that major disruptions are happening to computer science education around the world, and specifically, as it relates to domains like Quantum Computing. It is not a matter of whether Quantum Computing will pick up, but a matter of when. This disruption is likely to change computer science education starting from the theoretical foundations all the way to the methodologies, algorithms, and applications. With export restrictions put in place related to Quantum Computing infrastructure, computer science education in the Arab World faces real challenges and may encounter significant setbacks. With many regions around the world relying on graduates from the region, this may also have its impact on the global supply of computing professionals.

Nevertheless, and despite these challenges, computer science education in the Arab World has evolved over the years. Such evolution is expected to continue in the future which could be attributed to several directions that are currently being pursued by different programs across the region. One aspect is taking advantage of acquiring regular feedback and updates of the learning material according to the latest trends in the field. This is manifested by obtaining international accreditation for various programs in the region in addition to establishing a continuous dialog with the industry to better assess the quality of the graduates. In addition, another aspect that has seen progress in recent years is promoting experiential learning that has become central to many programs across the region by allowing students to develop projects, supervised by faculty, coached by graduate students, and co-mentored by industry partners.

The substantial number and high concentration of computer science students in the region along with their high levels of education and the potential they represent for the market indicate that they can easily grab their share of the global market that is in dire need of skilled computer science professionals. For instance, Dr. Jimmy Nassif, Chief Technology Officer of Idealworks and former Head of IT Planning Systems at BMW Group, stated during one of his latest trips to Lebanon: "The young and vibrant body of Computer Science/Engineering students and graduates in Lebanon is the new oil for the technology industry." The large number of computer science graduates in the entire Arab World with their high levels of education could very easily attract the technology giants from Europe and even from the USA and China to open up shop in this strategic geographic region, and employ the largely untapped resource that is the young Arab World computer science generation. The Arab World has the advantage of modest living expenses in most of its countries, which implies lower salary expectations compared to Europe and the USA. With the highly-skilled computer science calibers in the Arab World, this could represent a strong incentive for big technology companies to establish branches and headquarters in the Arab World. This is a beacon of hope for major education institutions in the Arab World, to maintain their high-levels of education, to build stronger academic collaborations with major international computer science programs, to boost their industry collaborations, to develop experiential learning programs, and to remain visible and ready to engage.

In addition to the significant efforts in the higher education sector, governments in the Arab World have been investing in their human capital to overcome shortage of the skilled taskforce with an emphasis on computing and engineering fields. This is evident, especially in the UAE and Saudi Arabia, where great investments by the governments and industry have established an ecosystem for innovations and entrepreneurship in areas such as AI, Blockchains, Cybersecurity, Data Science, and other computing related areas. Similarly, in Egypt, multiple initiatives sponsored by the government are paving the way to boost the skills of the graduates in AI and Data Science.

[M]ultiple directions must be pursued to provide more visibility and hence help to further improve computer science education in the region. … Leading computer science education and research conferences could be hosted in the Arab World, which would represent an excellent venue for computer science experts to explore on the ground the current capabilities in the Arab World in their own field.

In sum, this article represents an attempt to inform the community about the landscape of computer science education in the Arab World focusing on success stories across the region. Nevertheless, the visibility of computer science graduates from the region to the rest of the world remains undermined. Thus, multiple directions need to be pursued to provide more visibility and hence help to further improve computer science education in the region. First, joint programs could be offered in partnership with universities in the US and Europe, especially for programs that are already accredited by international accreditation bodies such as ABET since such offering would be simple to implement. Second, student exchange programs could be expanded to provide students with opportunities to spend at least a semester at leading institutes in the US and Europe, which will broaden their vision as they are exposed to the latest approaches in computer science education. Finally, leading computer science education and research conferences could be hosted in the Arab World, which would represent an excellent venue for computer science experts to explore on the ground the current capabilities in the Arab World in their own field.

The directions just discussed in addition to the continuous update of computer science curricula as manifested in this article, collaboration with the industry and obtaining international accreditation offers a roadmap for other universities within the Arab World and in other regions worldwide to cope with the rapid evolution in the computer science domain. Following these directions, computer science education and industry in the Arab World will be able to maintain a good momentum to become among the top in the World. ❖

References

1. AABET Find Programs. https://www.abet.org/accreditation/find-programs/; accessed 2023 Dec 10.
2. About | AUC School of Sciences and Engineering. https://sse.aucegypt.edu/departments/computer-science/about; accessed 2023 Sep 24.
3. About the American University in Cairo. https://www.aucegypt.edu/about/mission-and-history; accessed 2023 Dec 12.
4. About the Faculty of Computing and Information Science. Ain Shams University. https://cis.asu.edu.eg/page/2; accessed 2023 Sep 15.
5. Admission Grades at Egyptian Universities by Major. https://tansik.digital.gov.eg/Application/Certificates/Thanwy/Limits/LimitE2023.htm; accessed 2023 Dec 10.
6. AI-Movement at Mohammed VI Polytechnic University. https://aim.um6p.ma/en/home; accessed 2023 Sep 15.
7. Al Akhawayn University Royal Decree. http://www.aui.ma/en/security/safety-security/prevention/8-about-al-akhawayn/2416-royal-dahir.html; accessed 2023 Sep 15.
8. Alive and Well: The 2022 LAU Case Competition. https://news.lau.edu.lb/2022/alive-and-well-the-2022-lau-case-competition.php; accessed 2023 Sep 22.
9. ApplyInsights: International Student Interest in IT and Computing Programs on the Rise. https://www.applyboard.com/blog/applyinsights-international-student-interest-in-it-and-computing-programs-on-the-rise#:~:text=In%20the%202019%2F20%20academic,2019%2F20%2C%20behind%20Engineering; accessed 2023 Sep 24.
10. AUC Study Abroad Program. https://www.aucegypt.edu/index.php/academics/study-abroad; accessed 2023 Dec 12.
11. AUC Summer Semester Abroad List of Universities. https://www.aucegypt.edu/index.php/academics/study-abroad/summer-list-universities; accessed 2023 Dec 12.
12. Average weekly cash wage in L.E in Public sector/ public business and private sector in Egypt. https://www.capmas.gov.eg/Pages/IndicatorsPage.aspx?page_id=6152&ind_id=1100; accessed 2023 Sep 24.
13. Bachelor of Data Science. The American University in Cairo. https://sse.aucegypt.edu/programs/undergraduate/data-science; accessed 2023 Sep 24.
14. Bachelor of Science in Computer Science. United Arab Emirates University. https://cit.uaeu.ac.ae//en/programs/undergraduate/bachelor-of-science-in-computer-science.shtml; accessed 2023 Sept 22.
15. Bachelor Program in Computer Science. King Saud University. https://cs.ksu.edu.sa/en/bs-program; accessed 2023 Sep 20.
16. Big Data and Data Science Diploma - ITCS - Nile University. https://itcs.nu.edu.eg/program/big-data-and-data-science-diploma; accessed 2023 Sep 20.
17. Brain Drain Worries in Morocco. https://www.archyde.com/brain-drain-worries-in-morocco/; accessed 2023 Sep 15.
18. BSc Computer Science Degree Effat University. https://www.effatuniversity.edu.sa/english/academics/undergraduate/coe/pages/cs.aspx; accessed 2023 Sep 24.
19. BSc in Computer Science Khalifa University. https://www.ku.ac.ae/program/bsc-in-computer-science; accessed 2023 Sep 24.
20. CAPMAS Egypt. https://www.capmas.gov.eg/HomePage.aspx; accessed 2023 Sep 24.
21. Cardiff Metropolitan University in Morocco. https://sist.ac.ma; accessed Sep 15.
22. Center for Cybersecurity and Privacy at Mohammed VI Polytechnic University. https://www.um6p-cs.ma/en/cybersecurity-and-privacy/; accessed Sep 15.
23. The Centrale School of Casablanca. http://www.centrale-casablanca.ma/en/; accessed 2023 Sep 15.
24. CNEF. https://unesdoc.unesco.org/ark:/48223/pf0000216361; accessed 2023 Sep 15.
25. Commission for Academic Accreditation UAE. https://www.caa.ae/Pages/Guidelines/Standards.aspx; accessed 2023 Sep 24.
26. CSEE. https://www.leaders.com.tn/article/33803-fethi-sellaouti-ministre-de-l-education-les-defis-majeurs-de-la-rentree-et-l-imperatif-d-une-transformation-profonde; accessed 2023 Sep 15.
27. CSEFRS. https://www.csefrs.ma/?lang=fr; accessed 2023 Sep 15.
28. Destination Lebanon: A World-Class Supercomputing Center at the Service of Academic Research. https://news.lau.edu.lb/2022/destination-lebanon-a-world-class-supercomputing-center-at-the-service-of-academic-research.php; accessed 2023 Sep 24.
29. Digital Egypt Builders Initiative (DEBI). https://mcit.gov.eg/en/Human_Capacity/MCIT/Digital_Egypt_Builders_Initiative; accessed 2023 Sep 22.
30. DIPLOMA IN DATA SCIENCE at the German University in Cairo. https://www.guc.edu.eg/en/continuing_education/PostgraduateDiploma/IT/DataScienceDiploma.aspx; accessed 2023 Sep 24.
31. Distribution of Students on the Faculties of Computers and Information 2022-2023 in all universities in Egypt's governorates. https://www.elwatannews.com/news/details/6257314; accessed 2023 Sep 24.
32. Ecole Nationale Superieure d'Intelligence Artificielle. https://ensia.edu.dz/fr/; accessed 2023 Sep 15.
33. Entrepreneurship at UM6P. https://um6p.ma/fr/entrepreneuriat-0; accessed 2023 Sep 15.
34. The Erasmus+ Program. https://erasmus-plus.ec.europa.eu/fr/programme-guide/part-a/eligible-countries[accessed 2023 Sep 15.
35. European Commission, Education and Training: The Bologna Process and the European Higher Education Area. https://education.ec.europa.eu/education-levels/higher-education/inclusive-and-connected-higher-education/bologna-process. Accessed 2023 September 15.

36. The Faculty of Artificial Intelligence. Kafr Elsheikh University. https://kfs.edu.eg/en_ai/; accessed 2023 Sep 22.
37. Faculty of Graduate Studies for Statistical Research. http://issr.cu.edu.eg/ar/idept/computer-science/. Accessed *2023* September 20.
38. Faculty of Informatics and Computer Science. German International University. https://giu-uni.de/en/academic-specializations/informatics/. Accessed *2023* September 22.
39. FCI History. http://fci.cu.edu.eg/FCI_History. Accessed *2023* September 15.
40. FIRST LEGO League Debuts in the Region at LAU. https://news.lau.edu.lb/2019/first-lego-league-debuts-in-the-region-at-lau.php. Accessed 2023 September 22.
41. Future Engineers Gather at LAU for a NERD Battle. https://news.lau.edu.lb/2019/future-engineers-gather-at-lau-for-a-nerd-battle.php; accessed 2023 Sep 22.
42. High Performance Computing for Lebanon. https://hpc4l-webpage.web.cern.ch/; accessed 2023 Sep 22.
43. Higher education in Jordan: history, present status and future. https://qs-gen.com/higher-education-in-jordan-history-present-status-and-future/#:~:text=Jordan%20is%20home%20to%2010,students%2C%20and%2018%2C000%20graduate%20students; accessed 2023 Sep 24.
44. The Higher Education system in Palestine National Report. http://www.reconow.eu/files/fileusers/5140_National-Report-Palestine-RecoNOW.pdf; accessed 2023 Sep 20.
45. The Horizon Europe Program. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/widening-participation-and-spreading-excellence_en; accessed 2023 Sep 15.
46. Inside the BMW Internship | LAU News. https://news.lau.edu.lb/2019/inside-the-bmw-internship.php; accessed 2023 Sep 22.
47. International Credit Conversion Guide. https://sc.edu/about/offices_and_divisions/registrar/transfer_credits/international_credit_converstion_guide.php; accessed 2023 Dec 10.
48. Interview with Prof. Hassina Meziane from Oran 1 Ahmed Ben-Bella University. Interviewed by Karima Echihabi, 2022.
49. Interview with Prof. Lilia Cheniti from Sousse Univesity. Interviewed by Karima Echihabi, 2022.
50. Interview with Prof. Mohamed Jmaiel from ENIS-Univesrity of Sfax. Interviewed by Karima Echihabi, 2022.
51. Interview with Prof. Nadjet Kamel from Ferhat Abbas Setif 1 University. Interviewed by Karima Echihabi, 2022.
52. Interview with Prof. Tajjeeddine Rachidi from Al Akhawayn University. Interviewed by Karima Echihabi, 2022.
53. Iraq - Country Commercial Guide. https://www.trade.gov/country-commercial-guides/iraq-education-and-training-services#:~:text=In%20federal%20Iraq%2C%20there%20are,(exclusive%20of%20the%20IKR); accessed 2023 Sep 24.
54. LAU Faculty Forges Lasting Partnership with BMW. https://news.lau.edu.lb/2020/lau-faculty-forges-lasting-partnership-with-bmw.php; accessed 2023 Sep 22.
55. LAU's Vertically Integrated Project Wins Major International Consortium Awards. https://news.lau.edu.lb/2022/laus-vertically-integrated-project-wins-major-international-consortium-awards.php; accessed 2023 Sep 24.
56. LAU's VIP+ Innovation Showcase and Startup Competition Announces Winners. https://news.lau.edu.lb/2022/laus-vip-innovation-showcase-and-startup-competition-announces-winners.php; accessed 2023 Sep 24.
57. The Lebanese government needs to do more to improve the education sector. https://www.executive-magazine.com/opinion/the-lebanese-government-needs-to-do-more-to-improve-the-education-sector; accessed 2023 Sep 24.
58. Machine Learning Bootcamp a Hit | LAU News. https://news.lau.edu.lb/2022/machine-learning-bootcamp-a-hit.php; accessed 2023 Sep 24.
59. Mohammed VI Polytechnic University: Africa's most powerful supercomputer. https://www.um6p.ma/en/node/713; accessed 2023 Sep 15.
60. Moroccan Ministry of Higher Education: L'Enseignement Superieur en Chiffres. https://www.enssup.gov.ma/storage/statistique/2022/L'Enseignement%20Sup%C3%A9rieur%20en%20Chiffres%202021-2022.pdf; accessed 2023 Sep 15.
61. Moroccan National Defense Administration: Stratégie nationale en matière de cybersecurité. https://www.dgssi.gov.ma/sites/default/files/attached_files/strategie_nationale.pdf; accessed 2023 Sep15.
62. National Agency for Computer Security: National Stratefy for Cybsersecurity. https://ncss.ansi.tn/; accessed 2023 Sep 15.
63. National Council for Artificial Intelligence. https://mcit.gov.eg/en/Artificial_Intelligence; accessed 2023 Sep 22.
64. National Statistics Office. Statistical Yearbook of Algeria number 35 (2017). https://www.ons.dz/IMG/pdf/education_2017.pdf; accessed 2023 Sep 15.
65. Number of University Students in Lebanon. https://monthlymagazine.com/ar-article-desc_5078; accessed 2023 Sep 22.
66. Oracle Casablanca Research Lab. https://www.oracle.com/africa/news/announcement/oracle-opens-new-research-and-development-lab-in-morocco-2022-05-17/; accessed 2023 Sep 15.
67. PACTE ESRI. https://pactesri.enssup.gov.ma/; accessed 2023 Sep 15.
68. Practical Data Scientist Academy- Amazon Web Services. https://mcit.gov.eg/en/Human_Capacity/MCIT/Practical_Data_Scientist_Academy_Amazon_Web_Services; accessed 2023 Sep 22.
69. QS World University Rankings 2024: Top global universities. https://www.topuniversities.com/world-university-rankings; accessed 2023 Dec 10.
70. Reporters: Cyber sécurité : Un rendez- vous africain. https://www.reporters.dz/cyber-securite-un-rendez-vous-africain-en-novembre-prochain-a-alger/; accessed 2023 Sep 15.

71. Salary Explorer | Salary and Cost of Living Comparison. http://www.SalaryExplorer.com; accessed 2023 Sep 15.
72. Statistics Tunisia: Etudiants reguliers inscrits. http://www.ins.tn/statistiques/84; accessed 2023 Sep 15.
73. Students' Innovation Tops Google Solution Challenge. https://news.lau.edu.lb/2022/students-innovation-tops-google-solution-challenge.php; accessed 2023 Sep 24.
74. Study Abroad at the AUC List of Universities. https://www.aucegypt.edu/academics/study-abroad/undergraduate-list-universities; accessed 2023 Dec 12.
75. Syrian Universities Struggle to Survive After a Decade of War. https://www.al-fanarmedia.org/2021/04/syrian-universities-struggle-to-survive-after-a-decade-of-war/#:~:text=Sulaiman%20Mouselli%2C%20a%20professor%20of,academic%20staff%20members%2C%20including%20administrators; accessed 2023 Sep 24.
76. Times Higher Education Arab University Rankings 2023. https://timeshighereducation.com/world-university-rankings/2023/arab-university-rankings' accessed 2023 Dec 10.
77. Total number of graduates from government universities in Egypt. https://www.capmas.gov.eg/Pages/IndicatorsPage.aspx?page_id=6142&ind_id=1082; accessed 2023 Sep 24.
78. UNESCO: Maghreb-Mapping de l'écosystème de l'intelligence artificielle. https://fr.unesco.org/sites/default/files/20210526mappingecosystemeiadsmaghreb.pdf; accessed 2023 Sep 15.
79. The VIP+ Model | Programs - LAU MEPI. https://mepitl.lau.edu.lb/programs/college-to-work-pipeline/model.php; accessed 2023 Sep 22.
80. Vision Intelligence and Robotics Applications - VIRA 2020; https://eventscal.lau.edu.lb/event.php?evt=20201019_vision-intelligence-and-robotics-1; accessed 2023 September 22.
81. WebManagerCenter: Tunisie, Une enveloppe de 2,4 MDT pour financer la co-construction de parcours de formation. https://www.webmanagercenter.com/2020/02/05/444453/tunisie-une-enveloppe-de-24-mdt-pour-financer-la-co-construction-de-parcours-de-formation/; accessed 2023 Sep 15.
82. What are university educational credits - CFU. https://www.unibo.it/en/teaching/enrolment-transfer-and-final-examination/the-university-system/what-are-university-learning-credits-cfu; accessed 2023 December 10.
83. World Bank: World Population Indicators. https://data.worldbank.org/indicator/SP.POP.TOTL; accessed 2023 Sept 15.
84. Abdennadher, S., Aly, S.G., Tekli, J. and Echihabi, K. Unleashing early maturity academic innovations. *Communications of the ACM, 64* (4). 102-107. 2021.
85. Sanchez, E., Paukovics, E., Cheniti-Belcadhi, L., El Khayat, G., Said, B. and Korbaa, O. What do you mean by learning lab? *Education and Information Technologies*. 1-20. 2022.

Sherif G. Aly
Department of Computer Science and Engineering
The American University in Cairo, Cairo, Egypt
sgamal@aucegypt.edu

Karima Echihabi
Department of Computer Science
Mohamed VI Polytechnic University, Ben Guerir, Morocco
Karima.ECHIHABI@um6p.ma

Seif Eldawlatly (Corresponding Author)
Department of Computer Science and Engineering
The American University in Cairo
AUC Avenue, New Cairo, 11835, Cairo, Egypt
Ain Shams University, Cairo, Egypt
+20226152971 seldawlatly@eng.asu.edu.eg

Khaled Shuaib
College of Information Technology
United Arab Emirates University, Abu Dhabi, United Arab Emirates
k.shuaib@uaeu.ac.ae

Joe Tekli
Department of Electrical and Computer Engineering
Lebanese American University, Byblos, Lebanon
jtekli@gmail.com

DOI: 10.1145/3643036