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Unleashing Early Maturity Academic Innovations

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The Arab region consists of many teaching-intensive universities that are intrinsically committed to holistic educational excellence. According to a recent UNESCO report,[5] the higher education sector in the Arab region is undergoing a need for massive expansion given exponentially growing populations, record-breaking youth cohorts, coupled with a strong recognition of the economic and social value of higher education. Such an enormous need for growth poses a significant challenge for publicly funded universities yet offers many opportunities for private universities to meet the ever-increasing demands of advanced education.[2] As is the case with many similar universities worldwide, not being dedicated research institutions often results in limited availability of research funds, resources, and hence innovation throughput. The examples given in this paper are those of universities in the region that were initially focused on consolidating their teaching, except for one which started first as research-intensive. However, it was not long before a shift in policy included research excellence in undergraduate education by harnessing the most valuable resource of any university: the aspiring students themselves.

While the different universities followed seemingly different approaches to tap into undergraduate student potential, most successful models follow the same broad guidelines. The heart of stimulating high-quality undergraduate research innovation in computing lies in enabling full potential through early maturity, stimulation of discovery, exposure to international collaborations and projects while providing students with the needed freedom to grow and innovate. We take a shot at explaining how this is happening through four prominent universities from diverse areas across the Arab region.

The Enabling Ecosystem

Favorable conditions in the regional educational and societal system pave the way for successful undergraduate student transfor mations towards domain innovation, creativity, and excellence. For example, computing programs in the Arab region often attract the best students emerging from pre-university education. In most cases, the students are already enabled with a solid mathematical and scientific foundation by virtue of the anatomy of high school education and the accompanying conditions to qualify for university computing programs. On another front, computing education is trending in the region with a reputation for high market demand, a certain future, and high pay. Also, most prominent private universities in the region headhunt students by offering full and partial scholarships to top-ranking high school students. While STEM and computing specializations suffer from biased gender ratios in many regions, such as the United States and Europe, this type of education in the region is relatively gender-balanced compared to the rest of the world.[3] This balance makes the skill and interest pool of the students also relatively balanced and diverse. On the other hand, limited

research funding, a limited number of full-time graduate students, and a need to meet stringent requirements for academic rank progression led many university researchers to rely on undergraduate students early on. This is achieved by providing them with mentorship, incentivizing them to take on more responsibilities and tasks than usually accustomed for students at this level. Finally, a powerful desire from all involved parties for international collaboration, participation in pre-university computing competitions, and extracurricular work is deep-rooted amongst this type of pre-university student population.

The American University in Cairo (Egypt), the German University in Cairo (Egypt), the Lebanese American University (Lebanon), and Mohammed VI Polytechnic University (Morocco) are four private universities from diverse regions of the Arab world. They are relatively small in size compared to other regional counterparts. All of them started as teaching-intensive, except for the latter, which started as a research-intensive university before incorporating undergraduate programs. In the rest of the paper, we present the four different case studies of these universities and how they realized the early maturity approach for research and innovation.

The AUC Case Study

Since 1919, the American University in Cairo (AUC) has been a beacon of academic excellence in the region. The university was founded by Americans devoted to education and service in the Middle East, is strongly committed to liberal arts education, and strongly fosters critical thinking and creativity.[a] In 1988, the Computer Science Department was founded and later renamed to Computer Science and Engineering in 2008. The two programs were designed based on the highest academic standards of counterparts at North American universities and by the professional affiliations of its alumni. Many of the program alumni are working in highly impacting leadership and technical roles at Facebook, Dell, Google, Microsoft, MongoDB, Fujitsu, SAP, Amazon, Haliburton, Cisco, General Electric, UiPath, GitHub, NASA JPL, and more. Many have also either completed their education or have occupied academic positions at many leading universities around the world including Harvard, Carnegie Mellon University, Stanford, Boston University, Cambridge University, University of Alberta, Texas A&M, Northeastern, University of Waterloo, Columbia, MIT, and more. Others have initiated startups including the renowned Affectiva, Agolo, and Voicea. In 2018, the computing programs went through further radical changes to give more competitive edge to its graduates that included:

Early maturity. Course sequences were re-engineered to provide students at least one semester worth of earlier than usual maturity of technical content. Specifically, the first two fundamentals of computing courses that students take during the first two semesters in either Computer Science or Engineering were notably redesigned to accommodate more knowledge units. This included an in-depth study of problem-solving using C++ for a systems flavor, a notable coverage of data structures in both courses, more real life problems, and two formalized lab hours with both courses to offer a solid, mentored hands-on experience. Unnecessary prerequisites were removed to open opportunities for earlier than usual branching in the program of study, including an ability to take algorithm analysis and design (a key enabler) during the third semester as opposed to the fifth semester of study, as well as operating systems soon after. The idea of early maturity was to allow students an opportunity to learn and achieve earlier before fulltime engagement into the job market.

The Exploration Studio. Generous funds were made available to allow learners to experiment with computational technologies of their choice. At the end of exploration, students were required to "share and enjoy" their know-how. This provided students an opportunity to experiment with novel tools, share lessons learned, and also to help build an infrastructure for use by others. Within two years of inception, 16 proposals were submitted by groups of students of about three to five students each, some of which were required to be interdisciplinary. The funded proposals were in many areas including but not limited to autonomous vehicles, cybersecurity, nano-technology computing, embedded systems, and IoT.

Capstone empowerment. Besides rigorous technical requirements, capstone (thesis) projects must satisfy one or more empowerment outcomes: (a) produce a publishable innovation; (b) take a clear path toward productization; (c) serve a community purpose. Students were provided with sessions to boost their research and entrepreneurial capabilities. In Fall 2020, over half of the projects had a research element to them, so the standard of the project technicalities was notably boosted compared to previous semesters, and students were very engaged in undergraduate research activities. Projects in Fall 2020 alone included innovations in precision agriculture, healthcare for the elderly, fake news detection, human activity recognition, brain-computer interfacing, coronavirus diagnosis, visual speech recognition, and social augmented reality.

Entrepreneurial immersion. The Department of Computer Science and Engineering partnered with the university's Business School, and the first-ever satellite location of the university venture lab was created within the premise of the department. The idea was to bring the startup culture as close and as early as possible to the undergraduate student community so that students can observe and interact with counterparts in startups, and for the startups to export their technical challenges to the booming undergraduate population.

SPRITE branding. The programs were rightly branded as being Student Oriented, Popular, Research Intensive, Industrially Aligned, Technologically current, and Experiential. This was made visible in program activities so that the constituents of the computing programs were well aware of the vision.

Industrial training. The bar was raised for expectations related to industrial training so that students can benefit from an eight-week-long internship. Undergraduate students were also put in contact with alumni of the programs from prior years as a means of facilitating internships and employment.

Faculty. New vibrant, industrially experienced faculty were recruited to complement the existing body of faculty, some of whom were graduates from Ivy League universities with strong interdisciplinary backgrounds, and others with notable Silicon Valley industrial experience.

The GUC Case Study

The German University in Cairo (GUC) is an independent, private, non-profit Egyptian institution, led by a consortium of Egyptians and Germans focused on multidisciplinary cooperation between the two countries. It is the first integrated university outside Germany offering B.Sc., M.Sc., and Ph.D. degrees in 71 study programs. In its startup phase in 2003, the primary focus of the GUC was providing excellent teaching quality. After consolidating the teaching part, the policy shifted to follow the Humboldtian model[1,4] with a dual mission of research and teaching with unbiased and independent current research trends guiding curricula. The university continually expands in multiple senses in

response to the increased teaching demand. All university members, starting from the top faculty to the youngest students, are involved in this institutional framework of research and teaching unity. The GUC acknowledges the need for early involvement of young promising talents in the whole research and education lifecycle, where students are not only provided with technical and professional skills but are also allowed to seek growth and enabled to carve their education and professional path. Several diverse measures realize the following:

Research-oriented education. The curriculum consists of research- and industry-conscious courses, for example, the programming labs of each semester and the software engineering course. Most advanced courses (including electives and pre-masters) have research projects integrated into them with requirements that are adjusted according to current research trends and market needs. The course content is also flexible, allowing the integration of needed concepts and technologies.

Early publication motivation. Undergraduate students exploring research projects on their own or involved in bigger ones are mentored to publish their work in international conference proceedings. Bachelor thesis students are also encouraged to target publications based on their projects. Over the past five years, 50% of the GUC ICT publications resulted from undergraduate research.

Research environment exposure. Through various internal and external funds, students are exposed to numerous opportunities for participating in research and technical environments (not only through conventional internships). Over the past three years alone, the Faculty of Media Engineering and Technology hosted more than 25 international conferences, hackathons, workshops, and summer schools for students, promoting state-of-the-art technologies such as brain-computer interaction,[b] virtual reality, research best practices, and programming concepts. The GUC hosted the 17th International Conference on Mobile and Ubiquitous Multimedia (MUM'18),[c] as well as a number of workshops at international conferences including MUM'17, MUM'18, KI'19, and PAAMS'20.[d]

Involvement in cooperative research. As soon as students enter the university, they are offered the chance to join multiple research groups that enable them to join international research trips. This exposes them to international partners and various opportunities for enhancing studies through extended research trips and internships at partner institutions. The research groups' focuses include virtual and augmented reality, technology in education, self-driving cars, natural language processing, and character computing which take place in five dedicated labs (3D Lab, iLab, Cube, IoT Lab, and Self-driving Lab).

Startups and entrepreneurship. Many students who take the lead in shaping their research projects aspire to turn them into a startup. They find guidance and mentoring opportunities enabling them to seek such independence. Start-ups resulting from the GUC include Robusta,[e] Null Dies,[f] thndr,[g] and DREIDEV.[h] Many undergraduates work part-time in the industry or as freelancers.

Bachelor thesis abroad. Students are the bridge for joint research with German institutions and this international outreach. The bachelor thesis exchange program has been ongoing for the past 13 years, with a yearly average of 15% of students performing their bachelor projects at partner institutions in Germany and Europe. The same applies to funding opportunities by the German Academic Exchange Service for bilateral postgraduate studies abroad, thus increasing students' interests in an academic career early on.

STEM and computing specializations in education are relatively gender-balanced in the Arab region compared to the rest of the world.

The LAU Case of Student Centeredness

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 later 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. Founded in 1995, the School of Engineering (SOE) is LAU's crown jewel, leading the university in academics, innovation, administration, and research quality. The SOE has established a model for student-centeredness, revolving around six main pillars: empowering students, motivating students, promoting student collaborations, promoting undergraduate research, showcasing student achievements, and securing professional opportunities.

Empowering students through academic and professional clubs, encouraging them to highlight their scientific and social talents through a dozen vibrant student clubs. SOE currently houses 10 vibrant student clubs, grouping more than 800 students from all engineering majors: ASME, ASCE, AI, Emergent Technologies, Engineers Without Borders, IEEE, IISE, Google DSC, Robotics, and SPE. Since 2018, the clubs have organized around 40 activities (four per club) every year, including workshops, invited speakers, excursions, and social events, attracting large crowds of participants from inside and outside campus.

The idea of early maturity was to allow students an opportunity to learn and achieve earlier before full-time engagement into the job market.

Motivating students. High-impact hackathons and competitions are organized frequently with industrial partners, involving a large number of students in intensive competition type environments, while connecting with international partners for exposure and experience sharing. In 2018–2019, the SOE organized one international and four national completion events,[i] involving more than 2,500 student participants: *First Lego League (FLL)* 2019 international robotics championship, 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); *BMW Group Beirut Hackathon 2019* in collaboration with Nvidia and Oracle (72 participants); and the *Popsicle Stick Bridge Competition 2019* (250 participants).

Promoting interdisciplinary student collaborations. SOE and the School of Medicine have worked together to create a new interdisciplinary collaboration. For example, since 2018 medical students can initiate collaborative projects with engineering students in *Computational Health Informatics*. Other initiatives include a series of *E-mobility* projects, gathering students to work on projects related to electric transportation systems. SOE organized the first road tests of hybrid and electric vehicles in Lebanon[i] in January 2019 to assess their performance under local conditions. Also,

the school annually organizes the LAU Engineering Week including invited talks, workshops, activities, and an annual gala dinner to celebrate engineering.

Promoting undergraduate research. SOE is attempting to harness the energy of undergraduate students by launching undergraduate research courses in every engineering program and a research methods course in the honor's program. While the former allows motivated students to get a foretaste of research activities, the latter allows them to study the theoretical foundations of the research methodology and apply it in their senior projects. Since 2018, more than 35 undergraduate students have participated in research projects, most of them publishing their papers in international conferences or journals.

Showcasing student achievements. SOE has established many annual events aiming at showcasing student achievements. One such event is the *SOE Pioneers Day*, which invites distinguished SOE students and alumni to present their projects and experiences. Another event is *SOE Projects Day*[j] allowing SOE students to present their capstone projects in the presence of representatives from major industry partners (including Murex and CME Offshore, among others). SOE holds one of the highest student employability rates in LAU, with almost all students securing jobs within six months following their graduation.

Securing professional opportunities. Through SOE's Carreer and Placement Offic*e* and LAU Alumni Relations Office, the university helps its students secure the best internship and job opportunities in the market. One of the strongest internship programs has been established with the BMW Group automotive giant, where more than 60 students since 2018 have completed internships at the company's Logistics Robotics department in Munich.[j] SOE has also built strong ties with many multinational companies, including FEV France, Murex, FOO, InMind.ai, Mitsulift, among many others.

The UM6P Case Study

Morocco boasts a large number of teaching-centric institutions delivering undergraduate and graduate computer science degrees. In 2017, Mohammed VI Polytechnic University (UM6P) was established as the first research-intensive university in the country, with innovation integrated into its core. Below, we identify some key factors that helped boost innovation at the undergraduate level.

Graduate education foundations first. UM6P schools brought graduate programs to a level of maturity first before starting undergraduate programs. This helped each school embed a culture of research and innovation, which seamlessly propagated to undergraduate programs. For example, the School of Computer Science (UM6P-CS) launched a fully funded four-year Ph.D. program in 2018 and will offer a subsequent undergraduate degree in computer science by fall 2021. There are currently 36 fully funded Ph.D. students enrolled at UM6P-CS, one of whom holds a Google Ph.D. Fellowship. Research efforts by UM6P-CS students and faculty have led to publications in top venues.

Attracting and retaining top talent. UM6P-CS recruits top students by offering generous scholarships and a world-class campus experience. Moreover, it attracts faculty with notable international research experience by providing them ample startup funds, the financial autonomy to build research lab(s), and a reduced teaching workload. A large network of national and international partnerships allows students and faculty members to collaborate on large-scale projects with real potential to drive societal change. UM6P-CS collaborates with prestigious institutions worldwide on a

number of research projects, including *Byzantine-Resilient Coordinate Descent* and *Content-Agnostic Fake News Detection* (EPFL), *Scalable Machine Learning on Massive High-Dimensional Vectors* (Université de Paris), *Security and Localization of IoT Devices* (Northeastern University), *High Speed Free Space Wireless Communications* (Télécom ParisTech and KAUST), and *Arabic Dialect Identification* (Université de Montréal).

World-class resources. UM6P-CS taps state-of-the-art resources that enable innovative research and teaching. For instance, researchers have access to the powerful computing resources of the Benguerir Data Center (BDC), which has server rooms spanning 2,000 square meters, with a five-megawatt IT load. Besides, professors can use the services of the university's Digital Learning Lab to develop courses based on novel pedagogical approaches and share them with the community through the Digital Learning Platform (DLP). The BDC has been certified as a Tier III and Tier IV center by the Uptime Institute[k] and the DLP, containing over 400 courses, was made accessible free-of-charge to thousands of students nationwide since the onset of the COVID crisis.[l]

Turning ideas into reality. Students acquire interdisciplinary knowledge by developing and testing their ideas in real-scale experimental platforms such as living labs, experimental farms and mines, a green energy park, a smart building park, and a fab lab. The Technology Transfer Office supports university researchers in the commercialization of their inventions. Entrepreneurship is promoted within and outside the university with investment opportunities secured through venture capital firms and angel investors. 118 ideas have been supported so far through the pre-incubator programs Explorer and P-Curiosity Lab, in collaboration with MIT Sandbox. Ten projects are incubated by the U-Founders program, and 20 startups are supported by the Impulse accelerator program in collaboration with MassChallenge.

Innovation culture through location. UM6P-CS is located in the city of Ben Guerir, the first city in the African continent to participate in the Leadership in Energy and Environmental Design (LEED) Neighborhood Development certification process. This environment facilitates the development of technological innovations at the service of sustainable development. The university obtained a Silver level accreditation to the international standard Sustainability Tracking, Assessment & Rating System (STARS), awarded by the Association for the Advancement of Sustainability in Higher Education (AASHE).

Exchanging ideas. Prominent researchers from the Moroccan diaspora currently form the scientific advisory board at UM6P-CS. They are fully engaged in mentoring the next generation of researchers and supporting regional conferences. NETYS[n] is one such conference that has allowed, since 2013, hundreds of students, who do not have the means to attend conferences overseas, publish their ideas, and get feedback from eminent researchers and scholars.

Conclusion

We presented four case studies of diverse universities across the Arab region, as well as some of the enabling factors that contributed to the creation of a thriving culture of innovation and discovery at the undergraduate level. We shared some better practice guidelines that helped stimulate undergraduate research with the aim of initiating further discussions about sparking innovation among undergraduate student populations elsewhere in the region, and worldwide.

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Footnotes

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