CHAPTER 9

STEM Education in the Arab Countries: Rationale, Significance, and Future Prospects

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Abstract

The purpose of this chapter is four-fold: First, I present the rationale for STEM education at the pre-university level as it was conceived in the USA followed by the history of the development of STEM education and the various definitions and conceptualizations that were given to this approach across the past number of years. This is presented to elucidate the rationale for introducing STEM in the USA, the first country in which the concept of STEM was introduced, to benefit from the lessons learned that resulted from implementing STEM in the USA. Second, I provide evidence for the need for STEM education in Arab countries. Third, I describe different approaches used to implement STEM and discuss the research on the effectiveness of these approaches in improving achievement in and attitudes toward STEM fields as well as decisions to pursue STEM fields for further study in higher education. Fourth, I discuss the potential to improve the quality of learning in STEM subjects in Arab countries by adopting STEM education and the need to develop a home-grown form (or forms) of STEM that caters to the needs of Arab youth and Arab society.

Keywords

STEM education – Arab countries – Arab society – rationale for STEM – development of STEM – STEM approaches – home-grown STEM – STEM schools

1 Rationale for STEM Education at the Pre-University Level

What is this thing called STEM, and what is STEM Education? STEM is the acronym for science, technology, engineering, and mathematics (Breiner, Harkness, Johnson, & Koehler, 2012; Gonzalez & Kuenzi, 2012; Marrero, Gunning, & Germain-Williams, 2014). In the early 2000s, the National Science Foundation (NSF) in the United States of America coined "STEM" as an educational

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term (Dugger, 2010). The term was first used at the undergraduate level but has since been expanded to all educational levels. The acronym now implies more than the four subjects independently; it is considered in most situations the integration of science, technology, engineering, and mathematics into a new "whole", a cross-disciplinary subject in school (Dugger, 2010; Lantz, 2009). STEM education is thus considered an interdisciplinary approach to learning that offers students a chance to link different academic concepts with each other and with real-world issues as they learn and apply these four disciplines. However, the original meaning of STEM is still used in many circles. Zollman (2012, p. 18) suggested that "STEM literacy is the ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex problems and to innovate to solve them". These integrative approaches are expected to influence teachers' instructional strategies and students' attitudes toward and achievement in all these subjects positively. This, in turn, deepens students' understanding of content and engages them in higher-level thinking and problem-solving skills (Capraro & Han, 2014; Stohlmann, Moore, & Roehrig, 2012). Besides, STEM education is expected to prepare all students to use science appropriately in everyday life, especially since many of the problems that the world is currently facing have bases in science and technology (Kennedy & Odell, 2014). The Concept of STEM has been expanded to include art, resulting in the concept of STEAM (Yakman, 2009; Yakman & Lee, 2012) and medicine, resulting in STEMM (Solberg, Kimmel, & Miller, 2012). The focus in this chapter is on STEM.

2 Rationale for STEM Education in the USA

STEM education was conceptualized in the USA in response to the declining achievement in science and mathematics and the dwindling numbers of individuals selecting to major in science- and mathematics-related fields such as engineering and medicine, and technology-related fields at a time when these majors were necessary to keep the USA at the forefront of research, technology, and innovation (Lantz, 2009). Dugger (2010) showed that many students in the USA leave school without having a high school diploma, and a relatively small number of college graduates major in engineering. Dugger highlighted the fact that the USA is facing a consistent decline in homegrown STEM talent and becoming more dependent on foreign specialists to fill the gap. He further concluded by emphasizing the importance of making sure that students' interest is triggered just before they select their majors in college. This decline in numbers, however, is happening at a time when most people support the idea that the future of the USA rests on the existence of scientifically and mathematically literate citizens and a highly trained workforce; and on the availability of scientists, mathematicians, and engineers.

Another reason for the emergence of STEM was the relatively low ranking of the USA in international comparisons such as the Trends in Mathematics and Science Study[1] (TIMSS). It is worth noting that these results have improved significantly since 1995, the first time the US participated in TIMSS; nevertheless, it seems that the USA is still not satisfied with these results because they are considered as indicators of competitiveness. In 2015,[2] the average mathematics score of USA 4th-graders was 539 (13 countries above it), and USA 8th graders was 518 (nine countries above it), both higher than the international TIMSS scale average, which is set at 500. Similarly, the average science score of USA 4th-graders was 546 (nine countries above it), and USA 8th graders was 530 (10 countries above it), both higher than the international TIMSS scale average, which is set at 500. It is worth noting that the same arguments that focus on STEM subjects and STEM education are now echoed in many countries around the world; and the acronym "STEM" has become a popular "international" term when the quality of science, mathematics, technology, and engineering education is being discussed.

3 Rationale for STEM Education in the Arab Countries

The rationale behind adopting STEM education in several Arab countries is premised on the assumption that it has the potential to improve the quality of students' experiences in STEM subjects and, consequently, student achievement in these subjects. The concern regarding the quality of science education in the Arab countries resulted from the low performance of students in international comparison exams such as TIMSS and PISA and the relatively small number of students majoring in STEM subjects, factors akin to those identified in the USA. These concerns also resulted from other indicators of low-quality education in general and science education, more specifically, such as the relatively high levels of illiteracy, the low levels of access to the internet, the small number of internationally registered patents, and low productivity in scientific publications. These problems are discussed in the following pages.

What is the current state of mathematics and science education in the Arab countries, and does this state provide a rationale for STEM education? The two major problems that face Arab science education are access to and the quality of education. While the problems of access to education have been addressed in many Arab countries, as is evident from the increase in student enrollment at all educational levels, the problems of access to the internet and the quality of education are yet to be resolved. Even though many Arab countries have implemented or are implementing ambitious educational reform projects, access to the internet and the quality of student performance in mathematics and science is still lower than desired, as is evident from international comparisons. Moreover, the relatively small number of students pursuing science-related majors at the university level, the amount and quality of scientific research, and the number of registered patents is still problematic. This is especially serious because of the pressing need to prepare scientifically and technologically literate citizens who can function and succeed in the information age, where competition is extremely high, and knowledge is being produced at such a high rate that catching up is extremely difficult even for people who are highly educated and trained. In the following paragraphs, I discuss access to education, followed by access to the internet. This is followed by the quality of student achievement in science and mathematics, the quality and quality of scientific research, and the number of patents registered by Arab scientists.

3.1 *Access to Education*

According to the Regional Overview for Arab countries published by UNESCO in 2015,[3] there was an improvement in most Arab countries in terms of enrolment at all pre-college levels. At the pre-primary level, there was an 83% increase in the number of children joining pre-primary education, even though the overall enrolment at this level continued to be relatively low at 25% in 2012. At the primary level, there was a 22% increase in enrollment between 1999 and 2012, reaching approximately 89% in 2012. Projections by UNESCO for 2015 indicate that out of 15 Arab countries with data; nine are likely to achieve universal primary enrolment by 2015. UNESCO also asserts that increased enrolments resulted in a 43% decrease in the number of children not enrolled in schools. However, there was still a problem with dropout rates, with approximately 17% of students dropping out before completing primary education. Similarly, there was a significant increase in enrolment at the lower and upper secondary levels. On average, the gross enrolment ratio in the lower secondary level increased from 75% to nearly 89%, and that in the upper secondary increased from 45% to about 58%. However, there was a decrease in enrolment in technical and vocational education training (TVET) programs from 14% to 9% between 1999 and 2012 in 12 Arab countries with data.

3.2 *Access to the Internet*

The rapid proliferation of technology and access to the internet has provided people with the opportunity to have access to a wealth of potentially beneficial information that can be used in all walks of life (Cuban, 2003; Songer, 2007). People use technology and its applications along with the internet as tools to save time and effort and to solve complex problems along with many other uses. Similarly, instructional technologies have become the cornerstone of a technological revolution in all areas of education (Pedretti, Mayer-Smith, & Woodrow, 1998). Consequently, the need for integrating technology in the science classroom has become crucial in that today's students are growing up *with* technology and can learn science *through* technology (Prensky, 2001). Internet penetration is one indicator of the potential of educational systems in Arab countries to provide all stakeholders with opportunities to benefit from technology, especially the internet. Of course, this is premised on the meaningful use of the internet and other digital resources in the science classroom.

Table 9.1 presents the number of internet users and the percent penetration of the internet in the population of Arab countries along with other countries such as China, Singapore, and the USA. Hence, this table provides the opportunity to compare internet penetration among different countries. For instance, it shows that the penetration rates vary significantly among Arab countries with some of them higher than developing countries (Bahrain, Qatar and the UAE have higher penetration rates than France, Singapore, and the USA) and other very low: The lowest Arab state being Comoros (7.3%) and the highest Qatar (92.0%) and UAE (91.9%). It is also important to note that there are many Arab countries in which the penetration is below 50% (Algeria, Comoros, Djibouti, Egypt, Iraq, Jordan, Libya, Mauritania, Sudan, Syria, and Tunisia). For instance, it shows that the penetration rates vary significantly among Arab countries. For example, Comoros has the lowest penetration rate of 7.3%, while Qatar, UAE, and Bahrain have the highest rates of 92.0%, 91.9%, and 91.5%, respectively.

3.3 *Quality of Achievement in Mathematics and Science*

One indicator of the quality of mathematics and science education in Arab countries is the achievement of pre-university students in science and mathematics in these countries as compared to other countries. This comparison is possible in many Arab countries because the countries participate in two international comparison studies: The Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA). TIMSS was developed by the International Association for the Evaluation of Educational Achievement (IEA) to measure trends in students' mathematics and science achievement worldwide at grade 4 and 8 levels.[4] It provides participating countries with data that allow them to measure students' progress in mathematics and science achievement every four years.

TABLE 9.1 Internet users by country: Arab countries and selected other countries (2016)

Country	Internet users 2016	Penetration (% of Population)	Population (2016)	Users 1-year change (%)
France	55,860,330	86.4	64,668,129	0.42
Singapore	4,699,204	82.5	5,696,506	2.0
USA	286,942,362	88.5	324,118,787	1.1
Algeria	7,937,913	19.7	40,375,954	4.3
Bahrain	1,278,752	91.5	1,396,829	1.7
Comoros	59,242	7.3	807,118	3.9
Djibouti	105,163	11.7	899,598	4.0
Egypt	30,835,256	33.0	93,383,574	3.3
Iraq	4,892,463	13.0	37,547,686	7.5
Jordan	3,536,871	45.7	7,747,800	3.2
Kuwait	3,202,110	79.9	4,007,146	3.4
Lebanon	4,545,007	75.9	5,988,153	3.2
Libya	1,335,705	21.1	6,330,159	9.9
Mauritania	714,132	17.1	4,166,463	15.8
Morocco	20,068,556	57.6	34,817,065	1.7
Oman	3,310,260	71.1	4,654,471	4.1
Qatar	2,108,970	92.0	2,291,368	2.8
Saudi Arabia	20,813,695	64.7	32,157,974	2.8
Palestine	3,007,869	62.7	4,797,239	7.5
Sudan	10,886,813	26.4	41,175,541	4.5
Syria	5,502,250	29.6	18,563,595	2.0
Tunisia	5,472,618	48.1	11,375,220	2.4
UAE	8,515,420	91.9	9,266,971	1.7
Yemen	6,773,228	24.7	27,477,600	5.2

SOURCE: HTTP://WWW.INTERNETLIVESTATS.COM/INTERNET-USERS-BY-COUNTRY/

Tables 9.2 and 9.3 give the results of TIMSS for several Arab countries for the years 2007, 2011, and 2015. Results show that all Arab countries scored below the TIMSS Scale Center Point and below Singapore, one of the top scorers.

PISA, the other international comparison test, is an ongoing international assessment that measures 15-year-old students' reading, mathematics, and science literacy every three years. According to the National Center for Educational Statistics,[5] PISA also includes measures of general or cross-curricular competencies, such as collaborative problem-solving. By design,

TABLE 9.2 TIMSS mathematics and science scores in grades 4 in Arab and a selected number of other countries

	Math			**Science**		
Year	2007	2011	2015	2007	2011	2015
TIMSS **Scale Average**	500	500	500	500	500	500
Singapore	599	606	–	587	583	–
Algeria	378	–	–	354	–	–
Morocco	341	335	337	297	264	352
Tunisia	327	359	–	318	346	–
Kuwait	316	342	353	348	347	337
Qatar	296	413	439	294	394	436
Yemen	224	248	–	197	209	–
Bahrain	–	436	451	–	449	459
UAE	–	434	452	–	428	451
Saudi Arabia	–	410	383	–	429	350
Oman	–	385	425	–	377	431

SOURCE: HTTP://TIMSS.BC.EDU/ISC/PUBLICATIONS.HTML

PISA emphasizes functional skills that students have acquired as they are near the end of compulsory schooling. Furthermore, PISA aims to offer educators with insights that can be used to inform policy and practice by monitoring student acquisition of knowledge and skills across countries.[6] PISA defines scientific literacy as "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen". PISA's definition also includes being able to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically; and apply scientific knowledge in the context of real-life situations.[7] Table 9.4 shows that students in the Arab countries that participated in PISA score below the OECD average and significantly below Finland and Singapore, the two top-scoring countries.

3.4 *Students Pursuing Scientific Majors*

Even though there has been a significant improvement in enrolment at the pre-university level, the number of students who major in science, engineering, and agriculture is not yet at the level needed to enhance the quality of science and technology in related industries in the Arab countries. Table 9.5 presents the number of university graduates in science, engineering, and

TABLE 9.3 TIMSS mathematics and science scores in grades 8 in Arab and a selected number of other countries

	Math			Science		
Year	2007	2011	2015	2007	2011	2015
TIMSS Scale Average	500	500	500	500	500	500
Singapore	593	611	–	567	590	–
Lebanon	449	449	442	414	406	398
Jordan	427	406	386	482	449	426
Tunisia	420	425	–	445	439	–
Bahrain	398	409	454	467	452	466
Syria	395	380	–	452	426	–
Egypt	391	–	392	408	–	371
Algeria	387	–	–	408	–	–
Oman	372	366	403	423	420	455
Palestine (Authority)	367	404	–	404	420	–
Kuwait	354	–	392	418	–	411
Saudi Arabia	329	394	368	403	436	396
Qatar	307	410	437	319	419	457
Morocco	381	371	384	402	376	393
UAE	–	456	465	–	465	477

SOURCE: HTTP://TIMSS.BC.EDU/ISC/PUBLICATIONS.HTML

agriculture as a percentage of the total number of university graduates in 2012 or the closest year.[8] Table 9.5 shows that the percentage of students majoring in science and science-related fields range from a low of 11.9% in Jordan to a high of 44.7% in Tunisia.

3.5 *Scientific Research*

Conducting scientific research and publishing in international refereed scientific journals are indicators of the quality of researchers (and possibly research facilities and funding) and the involvement of the researchers in the production of scientific knowledge. The relevance of this issue to the quality of science education in Arab countries comes from the fact that publishing in refereed journals is a possible indicator of the quality of university faculty members and the overall experience of students in science at the university level. Table 9.6 presents the number of refereed papers published by researchers in several Arab countries compared to three developed countries: Germany, the United Kingdom, and France. Table 9.6 also presents the number of publications per

TABLE 9.4 PISA science scores in several Arab countries compared to Finland and Singapore

Year	2009		2012		2015	
	Science	Math	Science	Math	Science	Math
OECD Average	501	496	501	494	483	490
Singapore	542	562	551	573	556	564
Algeria	–	–	–	–	376	360
Jordan	415	387	409	386	409	380
Lebanon	–	–	–	–	386	396
Qatar	379	368	384	376	418	402
Tunisia	401	371	398	388	386	367
UAE	466	433	448	434	437	426

TABLE 9.5 Number of university graduates in science, engineering, and agriculture as a percentage of total university graduates in 2012 or closest year

Country	Year	Population 2013 (in millions)	Total in all Fields	Science, engineering, and agriculture	
				Number	% of total
Algeria	2013	35.7	255435	62356	24.4
Egypt	2013	75.5	510363	71753	14.1
Jordan	2011	5.8	60686	7225	11.9
Lebanon	2011	4.2	34007	8108	23.8
Morocco	2010	31.0	75744	27524	26.3
Palestine	2013	3.6	35279	5568	15.8
Qatar	2013	1.4	2284	671	29.4
Saudi Arabia	2013	26.4	141196	39312	27.8
Sudan	2013	34.0	124494	23287	18.7
Syria	2013	20.3	58694	12239	20.9
Tunisia	2013	10.3	65421	29272	44.7
UAE	2013	6.8	25682	5886	22.8

million people in the country to provide a possible measure to compare these countries. This table shows that the publication per million people in Arab countries is significantly lower than the three developing countries.

TABLE 9.6 Number of scientific publications by researchers in several Arab countries compared to Germany, the United Kingdom, and France

Country	2005	2014	2014 population (in millions)	Publication per million
Germany	73573	91631	82.0	1117.5
United Kingdom	70201	87948	63.9	1376.3
France	52476	65086	65.6	992.2
Egypt	2919	8428	82.0	102.8
Saudi Arabia	1362	10898	29.0	375.8
Tunisia	1362	3068	11.0	278.9
Algeria	795	2302	39.0	59.0
Morocco	990	1574	33.0	47.7
UAE	462	1450	9.0	161.2
Jordan	641	1093	6.5	168.2
Lebanon	283	1009	4.5	224.2
Kuwait	462	604	3.5	172.6
Oman	93	591	3.6	164.2
Sudan	–	309	38.0	8.1
Yemen	41	202	24.5	8.2
Bahrain	70	155	1.5	103.3
Mauritania	27	23	4.0	5.8
Palestine	27	24	4.0	6.0

SOURCE: HTTP://UNESDOC.UNESCO.ORG/IMAGES/0023/002354/235406E.PDF

3.5.1 Number of Registered Patents

Yet another indicator of the quality of science at the university level is the number of patents applied for and registered by researchers of a country because this number might indicate the commitments of the country to quality science and science education, the innovativeness and creativity of the scientists, as well as the different types of support that scientists receive. Table 9.7 presents the number of patents obtained by scientists in several Arab countries and three developed countries. These numbers show the relatively low numbers of patents applied for by scientists in Arab countries. As an example, the populations of Egypt and Germany were approximately the same in 2014. However, while Germany submitted 105,078 patent applications, only 851 applications were submitted by Egypt. Similarly, the population of Saudi Arabia was 29 million in 2014, almost one-third of the people of Germany, but the patents submitted by Saudi Arabia were almost 3% of those submitted by Germany.

To summarize, the data presented above provide strong evidence for the need to improve the quality of STEM education at the pre-university and university levels because of the need for scientifically literate citizens and specialists in the STEM, who are expected to improve the quality of life through active scientific and technological research and the production of essential technological and engineering tools.

4 Approaches to Teaching STEM

4.1 *Approaches to Teaching STEM in the USA*

The concept of STEM in general and STEM Education more specifically, were conceptualized in the USA. Moreover, strategies used to teach different approaches to STEM education are mostly developed in the USA. As a result, the proliferation of STEM education around the world was influenced clearly by what was performed in the USA. For these reasons, the development of STEM education in the USA must be described and discussed because of the possible influence and benefits that can be accrued from the experiences of USA educators in this area.

Since science, technology, and mathematics are integral to education systems around the world, it can be said that some STEM is being taught in virtually all schools. The only subject that was not included in traditional curricula is engineering, and this subject has been introduced in many schools in response to the call for strengthening STEM education and to the introduction of the Next Generation Science Standards (NGSS) (National Research Council [NRC], 2013). In an attempt to integrate STEM subjects, the NGSS identified the following eight science and engineering practices which are essential for all students: (1) Addressing questions (science) and defining problems; (2) developing and using models; (3) planning and running investigations; (4) analyzing and interpreting data; (5) utilizing mathematics and computational thinking; (6) constructing explanations and designing solutions; (7) engaging in argumentation from evidence; and (8) acquiring, evaluating and communicating information. These practices, along with the crosscutting concepts and disciplinary core ideas of science and engineering, are meant to help students to understand how scientific knowledge develops and to value the wide range of approaches that are used to investigate and explain the real world. Similarly, engaging in engineering practices provides students with the opportunity to understand the work of engineers, as well as the links between science and engineering.

According to the National Research Council [NRC] (2011), there are four broad categories of STEM programs in the USA. These are (1) Elite or selective

TABLE 9.7 Patent applications in Arab countries and several developing countries

	Year					
Country	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Germany	103,049	103,147	107,914	105,925	105,078	103,347
UK	27,904	26,464	28,877	28,191	28,467	28,897
France	32,484	32,298	34,115	34,549	35,298	34,760
Egypt	672	686	772	724	851	789
Saudi Arabia	845	921	2,025	2,694	3,114	2,678
Tunisia	118	150	162	129	157	200
Algeria	79	100	123	137	98	94
Morocco	152	176	207	333	359	258
UAE	90	171	193	271	315	362
Jordan	60	70	113	93	77	81
Lebanon	34	21	29	146	128	142
Kuwait	77	112	129	155	127	115
Iraq	2	4	16	4	6	342
Sudan	252	249	3	270	6	268

SOURCE: WORLD INTELLECTUAL PROPERTY ORGANIZATION (WIPO), HTTP://WWW.WIPO.INT/PORTAL/EN/INDEX.HTML

STEM-focused schools, (2) Inclusive STEM-focused schools, (3) STEM-focused career and technical education (CTE) schools or programs, and (4) STEM programs in comprehensive schools that are not STEM-focused.

– Elite or selective STEM-focused schools are very selective, enroll highly motivated students, and prepare students for admission to programs that prepare for STEM careers in elite universities.
– The Inclusive STEM-focused schools offer specializations in one or more STEM subjects but are not selective. These schools typically serve communities that are under-represented in STEM careers and prepare their students for entrance to universities.
– STEM-focused career and technical education schools or programs offer CTE education within comprehensive high schools in regional centers that serve many schools (Stone, 2011). Such programs are designed to prepare students for a broad range of STEM careers and often focus on engaging students at risk for dropping out of school.

– Many U.S. students are educated in traditional schools, and many of those schools do a good job at STEM education. Many high schools offer advanced placement and international baccalaureate courses for highly motivated students. Many STEM-related programs are available in middle and high schools, and some schools excel even without special programs.

STEM education can be implemented in a variety of ways using different combinations of subjects such as science and mathematics, science mathematics and technology, or science and technology, to name only a few (Bybee, 2013; Lederman & Lederman, 2013). However, the ultimate aim of STEM education is to implement "Integrated STEM" (Lederman & Lederman, 2013; Moore & Smith, 2014), which is an "effort to combine the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections among these disciplines and real-world problems" (Moore & Smith, 2014, p. 5). Integrated STEM has its roots in experiential learning (Kolb, 1984) and Dewey's (1938) progressive education movement and is sometimes akin to problem-based learning. More recently, 'arts' has been included in the assortment of subjects of STEM resulting in STEAM, which aims to integrate science, technology, engineering, the arts, and mathematics in an attempt to guide authentic student inquiry, encourage dialogue among different students with different interests and backgrounds, and promote critical and creative thinking. Additionally, integration of arts into STEM is made to prepare students to solve everyday problems which are imperfectly defined and constrained by missing knowledge, and whose solutions require multidisciplinary knowledge.

According to Moore, Guzey, and Brown (2014), high quality integrated STEM learning experiences include, but are not limited to, engaging students in engineering design challenges that allow them to learn from failure and participate in the redesign, using relevant contexts for the engineering challenges to which students can personally relate, requiring students to learn and use appropriate science or mathematics content, engaging students in content using student-centered pedagogies, and promoting communication skills and teamwork (p. 5).

Lantz (2009) suggested that implementing integrated STEM activities requires actions in which science, mathematics, engineering, and technology teachers plan and teach cooperatively. It is worthy to note that many educators are skeptical about the success of integrated approaches (Lederman & Lederman, 2013) because of the traditional emphasis on disciplines and solving of academic rather than everyday problems. According to McDonald (2016), the most current research in the field of education has been conducted with a disciplinary perspective rather than an integrated STEM perspective. However, there is a growing interest in integrated approaches to STEM education that have the potential to shed light on its effectiveness (Honey, Pearson, & Schweingruber, 2014).

Brown (2012) showed that the majority of STEM education research studies have investigated integrative STEM education. Moreover, Becker and Park (2011) showed that using this approach produces varying results depending on the type of integration and the educational level at which teaching takes place. In a meta-analysis related to the effect of using integrative STEM on students' learning, results showed that the most significant impact was at the elementary school level while the lowest was at the university level. Moreover, the integration of all four subjects produced the highest results while integrating engineering and mathematics, or mathematics, science, and technology, provided the lowest results. Cotabish, Dailey, Robinson, and Hughes (2013) investigated the effect of an intensive STEM professional development project, which focused on inquiry-based science and using a rigorous science curriculum on elementary students' science knowledge and skills. Results showed that there was a significant improvement in students' science process skills and science content knowledge. Scott (2012) investigated the characteristics of ten STEM high schools in the USA as well as the quality of graduates of these schools. Results showed that students at these schools followed a rigorous curriculum, were engaged in solving real-world problems, and completed internships or capstone courses. Moreover, graduates of these schools outperformed students at peer institutions.

4.2 *Approaches to Teaching STEM in Arab Countries*

Several Arab countries have started implementing STEM Education even though a literature search with the term "STEM" in Arab countries shows that the reference is to STEM subjects rather than to STEM education. Egypt has the most developed approach to STEM education as a result of the establishment of STEM schools for the gifted through financial support from donors such as the United States Agency for International Development (USAID) (refer to Figure 9.1). A 2015–2016 USAID report on STEM education in Egypt states that there are 11 girls' and boys' STEM Grade 10–12 schools distributed among several Egyptian governorates. However, the number of schools currently is 15. These schools have adopted a project-based pedagogy for the implementation of integrated STEM (Abd El Aziz, 2013; EL-Deghaidy, Said, & Matar, 2013; Rissmann-Joyce & El Nagdi, 2013; USAID, 2016). Additionally, work on STEM, and recently STEAM has been an area in which Egyptian universities have been relatively active. For example, the American University in Cairo has organized a Conference on STEAM[9] in 2013, established a STEM/STEAM center, The STEM Schools Project in Egypt was funded by the United States Agency for International Development (USAID) and implemented, starting in 2011, by the Egyptian Ministry of Education and Technical Education (MoETE) with support from a consortium of educational organizations namely World Learning, the Franklin Institute, the 21st Century Partnership for STEM Education, and the Teaching Institute for Excellence in STEM. Currently, 15 STEM secondary boarding schools[13] (Grade 9–12) have been established in several governorates around Egypt. These schools accepted around 2000 students during the academic year 2019–2019. MoETE has created a STEM Unit that is in charge of developing the curricula and exams, recruiting teachers and support staff, and maintaining the quality of the schools' infrastructure. Also, the schools have a national board constituted of the Ministry, USAID, and high-ranking officials, which takes the regulatory decisions regarding the running of the schools. Finally, the schools have a board of trustees that oversees the schools. MoETE is expanding the establishment of these schools, as part of its interest in nurturing talented people in STEM fields, due to Egypt's need to increase the number of students enrolled in the scientific stream of the secondary schools. Admission to the schools is competitive and requires passing an entrance exam. It is to note that the names of these schools in Arabic are translated as "Schools for the Gifted in Science and Technology".

According to MoETE, the purposes of establishing STEM Schools in Egypt are to strengthen national identity and belonging, nurture students excelling in science, mathematics, engineering, and technology, implement new rigorous curricula and teaching methods that rely on inquiry projects and the integrated approach to teaching, and achieve complementarity between science, mathematics, engineering, and technology curricula and highlight the extent of the linkages among them. Besides, these schools aim to prepare students who can design and think creatively and critically, work cooperatively, and have a strong scientific base and research skills that qualify them to join STEM fields at the university level.

Several studies described the nature of Egyptian STEM schools and their curricula (e.g., Abd El Aziz, 2013; EL-Deghaidy & Abbas, 2013; Elnashar & Elnashar, 2018; Golam & Mansour, 2015). Likewise, AbdelMeguid (2017) conducted a case study with two STEM schools in which she investigated their governance and administrative structure and students' opinions about their experience in the schools. Results showed that graduates believed that the schools provided them with a unique learning opportunity that allowed them to join top universities in Egypt and abroad in the fields of their choice. Moreover, they agreed that the schools "gave them the space to get creative and follow their passions, as a result of the open research teaching technique" (p. 109). However, AbdelMaguid (2017) found that the schools were facing challenges with curriculum design and assessment criteria, teacher professional development, and the lack of compatibility between STEM and official curricula.

FIGURE 9.1 The STEM schools project in Egypt established a professional educators' diploma in STEAM,[10] and launched the first free Arabic massive open online course on STEAM education[11] (Gholam & Mansour, 2015; EL-Deghaidy, 2015, 2017; Purinton & ElSawy, 2014). Similarly, Ain Shams University in Cairo, Egypt, is planning to establish a STEM education department within the Faculty of Education (Khadri, 2014).

Saudi Arabia is another Arab country in which STEM Education has been introduced, albeit to a minimal extent (EL-Deghaidy, Mansour, Alzaghibi, & Alhammad 2017). Algeria has also established a STEAM center that is an "industry-led initiative to strengthen the innovation, critical thinking, and communication skills of the Algerian workforce via direct training of youth-targeted training of teachers, and community education forums and events".[12]

Other recent initiatives related to STEM education in Arab countries include a Master's degree in education with an emphasis on STEM offered by the Lebanese American University that began during the academic year 2014–2015. The mission of the program is "to prepare aspiring professionals in the field of education to become leaders, change agents, effective educational practitioners, and educational researchers".[14] Students in the program are required to take four core courses, one elective course, and three courses in the chosen emphasis. The core course courses include a curriculum design course, a research methods course, an educational technology course, and a course in advanced educational technology. The three courses in the STEM emphasis are "Pedagogical and Cognitive Foundations of STEM Education", "Trends and Issues in STEM Education", and "Research in STEM Education". The course entitled "Pedagogical and Cognitive Foundations of STEM Education" offers students the opportunity to "gain insights into the cognitive foundations and the pedagogical strategies that can enhance STEM education". The "Trends and Issues in STEM Education" course focuses on the nature of science and mathematics and their philosophical, societal, and cognitive bases in addition to the opportunities and challenges of using different STEM approaches. Finally, the "Research in STEM Education" provides students with opportunities to analyze and synthesize research approaches used in research studies focused on STEM in preparation for developing research proposals on a STEM-related topic. In addition to the above, students are required to complete a thesis or a project and complete a zero-credit course that requires them to participate in workshops, attend defenses of theses, and make at least one presentation other than the research proposal or thesis defense. Examples of the theses completed by students who graduated from the programs include (a) Implementing the STEM approach in the third grade of a school adopting the PYP (Primary Years Program), (b) Bringing a maker-centered classroom into the lower elementary classroom, and (c) Implementation of integrated STEM education within classrooms: A case study.

According to a faculty member who was behind the establishment of the program, the program provides students with pedagogical and cognitive tools to address everyday problems in which the integration of science, mathematics, technology, and engineering are needed and in which the engineering design process is necessary for solving the issues. According to her, this program meets the needs of schools that are starting to introduce STEM in their curricula and are interested in introducing their students to solving problems that entail the integration of STEM subjects because they also require students to use critical and creative thinking skills. Currently, the Lebanese curriculum does not focus on STEM education, and consequently, many Lebanese schools have introduced STEM as clubs, elective courses, or as individual projects.

Kuwait is another Arab country where STEM Education is being promoted. The Center for Teaching, Learning, and Research (CTLR) at Gulf University for Science and Technology (GUST)[15] in Kuwait established a partnership with the Kuwait Foundation for the Advancement of Science (KFAS) to support and provide the community with innovative educational projects related to STEM education. The main aim of the CTLR-KFAS collaboration was to equip 30 science and mathematics supervisors with essential knowledge and skills in STEM and train them to integrate STEM in the Kuwaiti school curriculum. As a result, STEM experts from the American University of Beirut (AUB) were invited to develop a STEM professional development model that addresses these needs and serves as an exemplary model for STEM training.[16] Based on several STEM training sessions conducted over the past five years (2015–2020), the lead STEM expert proposed the following model that encompasses seven components (Figure 9.2). Importantly, the model supported trainees in learning and practicing essential scaffolding skills such as working in teams and providing constructive feedback, two skills that are indispensable for the effective implementation of STEM activities.

The themes of the training sessions were distributed across five days (25 hours in total). Each training day included a theoretical part and a practical part. The theoretical part introduced participants to the pedagogical and cognitive foundations of STEM education, such as design thinking, integration, experiential learning, using concrete manipulatives, and multiple representations. The practical part included coding and non-coding activities, such as applying design thinking in solving a problem regarding toxic popcorn, building a wind turbine, building an air pollution detector, generating electricity from potatoes, recycling of e-waste, and building a solar tracker.

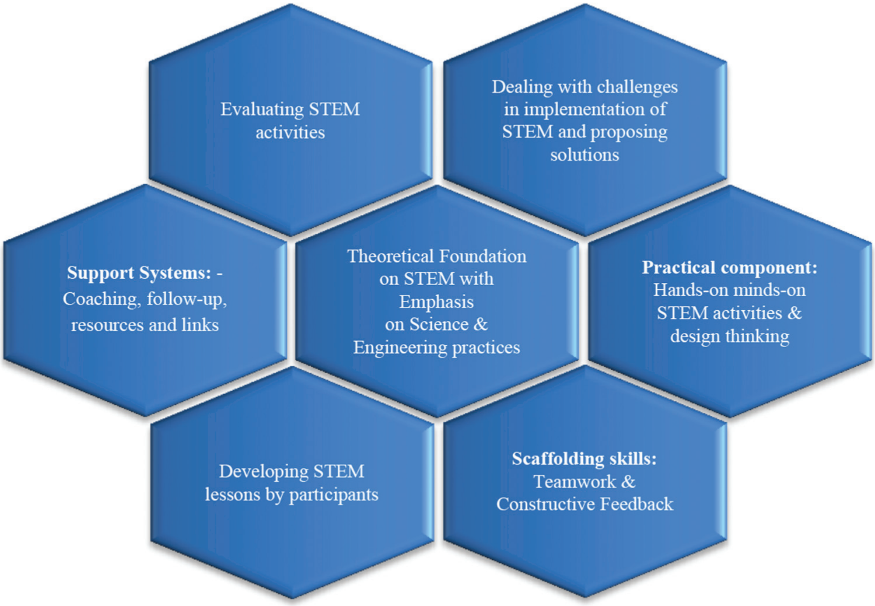

FIGURE 9.2 Model for designing STEM training

Each of these activities was followed by 15 minutes of reflection in which participants identified the science, mathematics, technology, and engineering concepts and skills highlighted in these activities, and that are useful to students. On day 5, participants from different areas of specialization selected a theme from their science curriculum and were asked to draft a STEM activity regarding that theme. Then, each group presented its activity and was asked to identify the underlying crosscutting concepts and processes used in their design, describe the originality and uniqueness of their activities, and explain how the designed activity serves students. Groups were encouraged to evaluate their peers' activities and provide suggestions for further improvement. One of the lessons learned from this experience in that providing STEM activities and training alone does not ensure that teachers become competent in applying STEM in their classrooms. To achieve such a goal, trainers should provide participants with strategies that can facilitate their adoption of STEM education. For example, participants unanimously reported that reviewing an already-developed STEM lesson and thoroughly analyzing it before developing their lessons was not only beneficial but also an extremely rich learning experience. Additionally, teachers need to be allowed ample time to design, apply, and receive feedback on their STEM lessons. In this respect, participants recommended providing clear criteria to be used for self-assessment, peer assessment, and expert assessment.

A third approach used to introduce STEAM activities in a school comes from Lebanon. In nearly 130 years of operation, this school has had a strong reputation in Lebanon as a school that promotes critical thinking, innovation, and collaboration. Through its guiding statements, the school is committed to creating an innovative learner-driven technology program that supports STEAM (Science, Technology, Engineering, the Arts and Mathematics), media literacy, and responsible digital citizenship and prepares learners for a competitive digital world. The school offers four programs at the secondary school, namely, the International Baccalaureate, Lebanese Baccalaureate, French Baccalaureate, and College Preparatory Program.

In addition to the existing state-of-the-art science laboratories, the makerspace, and computer laboratories, the school is creating an innovation center to integrate STEAM into its curriculum and campus life. This center comprises ten laboratories that are being equipped to host coding, filmmaking, robotics, digital art, design technology, and 3-D design/printing classes. The school is using the Lebanese technology curriculum for middle school in addition to the official French Baccalaureate Technology curriculum. In addition to K-12 educational technology integration in all subjects, the school also offers computer science courses to all students to promote computational and design thinking. Students in all four programs at the secondary school mentioned above will benefit from the STEAM laboratories ensuring a better understanding of these subjects. Another essential aspect of STEAM education is that all students from all backgrounds can be introduced to these fields at an early age. Through the STEAM program, the school aims to allow all its students to explore and discover the tools required to excel should they decide to take their careers in that direction. STEAM laboratories, the makerspace, and the science laboratories are also used by Lebanon's Center for Education Research and Development (CERD)[17] to pilot projects that can be integrated into the national Lebanese curriculum. This will help to strengthen the Lebanese curriculum for all students in the country.

Even though there are attempts to adopt STEM and STEAM approaches in the Arab countries, integrated STEM education has not been the focus of research in these countries; and as indicated by McDonald (2016), science education research in the Arab countries has been conducted along disciplinary lines. A study conducted by Ayoubi (2017) illustrates this point. Ayoubi (2017) conducted a study that aimed to analyze science education research studies published in Arab education journals and indexed in the Arab Educational Information Network (Shamaa) database. According to its website,[18] Shamaa indexes "peer-refereed articles, master theses, Ph.D. dissertations, books, reports and conference proceedings dated 2007 onward in Arabic, English, and French. The database includes bibliographic information, abstracts, and, when available, the full text of educational studies".[19] Ayoubi (2017) analyzed 122 science education research studies published between 2011 and 2015 in 38 out of 99 Arab education journals indexed in Shamaa. Ayoubi found that most articles included research studies related to general science while the few remaining studies were distributed among physics, chemistry, biology, and earth science education. Moreover, the examined topics focused on teaching, educational goals and objectives, and assessment in specific subject areas. Specifically, the studies investigated the following topics: In-service and preservice teachers, teaching, learning, students' conceptions, and conceptual change, learner characteristics and learning environment, goals and objectives, curriculum, assessment, social and gender issues, epistemology, history and philosophy of science, nature of science, using technology in science teaching, and informal education; thus, indicating that STEM was not a focus of research.

5 Improving the Quality of Learning in STEM Subjects in Arab Countries

What approaches can be used to introduce STEM Education in Arab countries? There are varied approaches for introducing STEM education in Arab countries. The four options presented by the NRC (2011) are all viable alternatives; even a homegrown approach is possible. Rather than selecting one model or approach, it might be useful to offer STEM education in a variety of forms to meet the needs of students. What structure and approach are selected is not the issue. The issue is rather in how to implement the selected approach for maximum benefits, what mechanisms to use to evaluate and improve the different approaches, how to improve the quality of teaching and learning in all these approaches, and more importantly, what principles of education the implementers of STEM programs can adopt. Below I provide possible answers to the above concern.

5.1 *How do We Implement the STEM Approach We Select for Maximum Benefits?*

First, the approach that is selected must be based on a careful analysis of the specific needs of the students, schools, and community. Grounding the approach in the needs of students and other stakeholders will increase the possibility of success. Implementation requires a systemic approach that includes the development of appropriate curricula and activities, the preparation of competent teachers, the planning of professional development activities aligned with the new approach, and the modification of the assessment activities. Jumping into implementation to catch up with what is going on in other countries without proper planning may fail and result in the demoralization of those involved.

5.2 *How do We Improve the Quality of Teaching and Learning in All These Approaches?*

Success in any of the above approaches hinges on the quality of teaching and learning that takes place in the classroom. It is understood that the quality of the teachers is a determining factor in this process. Research has shown that the following features are associated with relatively more effective teacher preparation (Allensworth, 2011): (1) requiring teacher candidates to take more courses in the content area; (2) requiring a capstone project (e.g., a portfolio of work done in classrooms or a research paper); (3) providing teacher candidates with practical coursework to learn specific practices; (4) providing teacher candidates with sufficient opportunities to learn about the curriculum in their region or country; and (5) providing student teaching experience, carefully overseeing that experience, and ensuring that that experience is consistent with later teaching assignments. However, it is also essential to agree on the principles that should drive whatever is needed to improve the quality of teaching and learning. In the case of STEM or STEAM specifically, teachers need to acquire an excellent foundation in their disciplines and the methods of teaching the discipline as well as integrated topics, the ability to work with others to design and implement STEM or STEAM curricula and lesson plans, and the methods of assessment of products of work on STEM activities.

5.3 *What Mechanisms Should Be Used to Evaluate and Improve the Different Approaches?*

Evaluation for improvement and research on the effectiveness of implementing STEM education projects should be integral components of any STEM program (and other programs). Evaluation and research should be conducted at all levels and by all stakeholders. However, this should be done with the aim of improvement. The viability of the programs cannot be based on their success in “other places” or on the results of research conducted in contexts that might be “foreign” to the culture of the Arab country in which STEM education is implemented by people who may not understand this culture. It is essential that all those involved in STEM education be trained to understand the context in which the research takes place, conduct “research” in its different forms (action research, qualitative research, quantitative research, etc.), and collect accurate data that can be used as a basis for decisions regarding school improvement.

5.4 *Implementing STEM Programs Successfully in Arab Countries*

Enhancing the possibility of success in implementing STEM programs in Arab countries requires that this implementation be based on sound principles derived from educational research. Resnick (2000) identified nine principles of education derived from a synthesis of research in psychology and education that, according to her, will define the nature of successful education in the twenty-first century and will draw attention to practices that may result in enhancing the quality of student learning. These are (1) organizing for effort, (2) clear expectations, (3) fair and credible evaluations, (4) recognition of accomplishment, (5) academic rigor in a thinking curriculum, (6) accountable talk, (7) socializing intelligence, (8) self-management of learning, and (9) learning as an apprenticeship.

The above principles provide essential aspects of education that should be taken into consideration when developing plans to implement STEM education with the understanding that actualizing these principles requires that the prevailing culture of schools is not "shocked", thus leading to resistance to change. The relevance of these principals to STEM education is evident because students enrolled in STEM are required to exert the needed effort to succeed, will benefit from clear expectations and fair evaluations., and would be encouraged to continue working hard if they are recognized for their accomplishments. It is also crucial that STEM curricula be rigorous and focus on thinking and that students' oral and written arguments be based on evidence. Furthermore, thorough argumentation, students are socialized to use the skills of intelligent thinking that will help them address complex and controversial issues that require the use of concepts and methods inherent in STEM subjects. Finally, succeeding in STEM subjects requires that students manage their learning properly and be guided by competent mentors.

Schools in the twenty-first century should convey the message that effort, not only ability, produces high achievement for ***all*** students. Therefore, with appropriate support, all students can develop skills, knowledge, and attitudes that would help them excel and succeed in all subject areas. Additionally, effort-based schools have clear and high expectations for all students. These expectations are understood and shared among all stakeholders in schools, including school administrators, teachers, parents, the community, and especially students. Thus, all students should be expected to achieve high minimum standards in all subject areas in the curriculum, particularly in mathematics, science, and technology, because these provide them with the tools to succeed in a scientifically and technologically saturated world. Mediocrity should not be accepted in these schools because it has the potential to widen the gap between those who have access to appropriate knowledge and those who do not.

However, if students are expected to exert the effort to achieve high and challenging standards, their evaluation should be fair and credible. Evaluation should be seen as fair and credible for all stakeholders and, thus, not limited to students, parents, and school professionals. Rather, the community, including the business community and institutions of higher education, should acknowledge this credibility. In the competitive environment of the new global community, society in general, and the business community, more specifically, cannot afford to re-teach students who have just graduated from high school. They expect high school graduates to have mastered knowledge and skills and developed positive attitudes on which they can build and which they can transfer from one domain to another. It is no more sufficient to teach students the "what" of knowledge but rather the "how" which will equip them to be knowledge producers rather than passive consumers. Fair and credible evaluations help members of the public and the business community to trust and support pre-college education. The issue of fair and credible evaluations is central to education. Thus, it is inadequate to give students theoretical examinations to evaluate tasks that require manipulation of equipment, solving problems, or addressing science- and technology-related issues and other practically oriented subject matter, especially in technical and vocational education. The credibility of evaluation is intimately associated with alignment between what is measured and how it is measured.

When students exert the effort to achieve high and demanding standards, and when evaluations are fair and credible, students' authentic achievement should be recognized. It is worth noting here that recognition of students' performance should be both formative and summative through which students are guided and helped to produce high-quality independent work that is suitably recognized.

Curricula in the 21st century schools cannot continue focusing on old basics. Critical thinking and problem-solving should be the new basics in the new millennium. Learning and teaching content that is disconnected from students' lives and society is unacceptable. Also, what's unacceptable is teaching thinking and problem-solving skills independent of the subject matter. Thinking and a solid foundation of knowledge are inseparable. In other words, it is impossible to teach content without teaching thinking skills and thinking skills without content matter.

Moreover, teaching thinking associated with the content matter should not be limited to programs for the gifted, as is currently the case in many schools and societies. As mentioned above, thinking and problem-solving are the new basics; consequently, they are important in all branches of secondary education, particularly in technical and vocational education. Being "intelligent" is a social activity that requires many problem-solving and reasoning abilities, along with the preparedness to use those capabilities regularly. These abilities develop when teachers expect students to use them and provide opportunities for students to practice them. Thus, all students in the twenty-first century should be helped to develop critical thinking skills and a strong foundation of content that will make them productive and successful citizens.

Curricula at all education levels and in all subject areas should be rigorous and organized around major concepts that allow the student to think and solve genuine and meaningful problems. If a rigorous thinking curriculum is advisable in all subject areas, it is essential in science, mathematics, and technology. The rate at which scientific knowledge is produced and technological advances are developed necessitate the emphasis on thinking and mastery of core concepts, thinking and problem-solving skills, and skills for life-long learning. It also requires that students learn and apply science inquiry and investigative skills; and understand the nature of science as well as the relationships between science, technology, and society.

The nature of classroom discourse and its possible relationships to learning has been an active area of research in education. This research has demonstrated that allowing students to talk in the classroom is not sufficient by itself. What matters is that this classroom talk is accountable to the learning community, to correct and appropriate knowledge, and rigorous thinking. Accountable talk takes place within a community of learners, draws on evidence relevant to the discipline such as data from investigations in science, and follows appropriate logical standards. When used appropriately, accountable talk improves students' thinking and allows them to construct meaningful knowledge. Accountable talk is akin to scientific and technological inquiry in that its arguments take into consideration the experiences of others along with new evidence to produce new claims. Helping students to use "accountable talk" at all education levels should be instrumental in preparing them to be lifelong inquirers.

The above principles do not work if students depend totally on teachers for their learning and for evaluating their work. Consequently, students who think rigorously and use accountable talk need to develop a set of self-monitoring strategies that will help them manage their learning personally. These strategies are essential characteristics of scientifically and technologically individuals who are continually attempting to decide what new knowledge and skills they need to acquire to stay updated in an ever-changing and expanding scientific and technological environment.

Finally, schools of the twenty-first century have to benefit from the knowledge base about apprenticeship learning because of its possible implications for education. Apprenticeships help students gain sophisticated interdisciplinary knowledge, learn the norms of professional communities, develop practical abilities and skills in a natural setting and, more importantly, create authentic products under the supervision of skilled experts. Schools can benefit from creating environments that approximate the natural setting to maximize students' learning. For example, they can place students for short periods in settings – such as research and development laboratories or technology companies – that will help them develop knowledge, skills, and attitudes about science, technology, and the workplace.

6 Conclusion

There is a pressing need to improve the quality of science and mathematics education in Arab countries. The gloomy picture of science and mathematics education presented above should give educators and policymakers the incentive to put the effort needed to improve the education of current and future generations. Because the traditional approach to reform education in Arab countries has not resulted in improved student performance, new approaches must be used. If planned and implemented appropriately, a STEM approach has the potential to produce positive results on condition that it be implemented by using instructional materials developed and validated locally, be adapted to the needs of Arab students and Arab countries, and be evaluated by researchers who have in-depth knowledge about Arab countries. Moreover, the success of implementing a STEM approach requires changes in assessment and teaching practices and the preparation of teachers. Borrowing approaches that have worked in the West does not guarantee their success in an Arab context – or actually in any other context that is different from the original one where the approach was initiated and used. Considering the above conditions, educators in schools and universities in the Arab countries can create environments where innovations such as STEM or STEAM succeed and ensure that students are prepared to live and work successfully in the 21st century.

Notes

1 https://timssandpirls.bc.edu
2 The mathematics and science results were acquired from https://nces.ed.gov/timss/timss2015/
3 Refer to https://en.unesco.org/unesco_science_report/arab-States and https://en.unesco.org/gem-report/sites/gem- report/files/157267E.pdf

4 In addition to tests at the Grade 4 and 8 levels, TIMSS also administers an "Advanced TIMSS" test. However, I present the results of Grade 4 and Grade 8 only because very few Arab States participated in Advanced TIMSS (only Lebanon participated in the exam in 2015).
5 https://nces.ed.gov/surveys/pisa/
6 https://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf
7 Refer to page 50 of http://www.keepeek.com/Digital-Asset-Management/oecd/education/pisa-2015-results-volume-i_9789264266490-en#.WhY2S1WWbcc#page52
8 UNESCO Institute of Statistics, July 2015.
9 http://schools.aucegypt.edu/GSE/Pages/STEAM-Education-in-Egypt.aspx
10 http://schools.aucegypt.edu/GSE/Programs/Pages/STEAM.aspx
11 https://www.albawaba.com/business/pr/auc-launches-first-free-arabic-massive-open-online-course-steam- education-cooperation-ed
12 https://www.worldlearning.org/program/algiers-steam-center/
13 Refer to http://moe.gov.eg/stem/ and http://moe.gov.eg/STEM/doc/steam2019-2020_V2.pdf
14 https://catalog.lau.edu.lb/2018-2019/graduate/programs/ma-education.php
15 https://www.gust.edu.kw/ctlr
16 I acknowledge Dr. Fatima Al Hashem, Director of CTLR at GUST and Dr. Enja Osman, STEM Expert, Department of Education, American University of Beirut who initiated and implemented this activity and provided me with the information to write about it.
17 http://www.crdp.org/?la=en
18 http://www.shamaa.org/en/component/About/about.asp
19 http://www.shamaa.org/en/component/main/index.asp

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